



NASA

Human/Robotics Systems

ROBEX Initial Meeting
Bremen, Germany
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Project Manager: Dr. Bill Bluethmann,
NASA Johnson Space Center

Presented by: Robert P. Mueller
NASA Kennedy Space Center

Human/Robotic Systems (HRS) Introduction



- Humans are more productive through the use of robots and human-robot teaming
- For this to work, the robots must be safe
 - Developing safe robotics will have applications on earth
- Laying out roles is critical in human-robot teams
- Development in computing, sensing, batteries, algorithms, common tools that make this a good time for robotics to flourish

HRS Introduction



- Robots and human-robot teams needed across all phases of missions
 - Preceding crew arrival
 - Working with humans during a mission
 - After crew departure
- How robots are controlled varies on mission phase and operation mode
 - Supervised from ground under time delay
 - Direct crew interaction
 - Riding on
 - Working shoulder-to-shoulder
 - In-direct crew interaction through teleoperation

HRS Approach



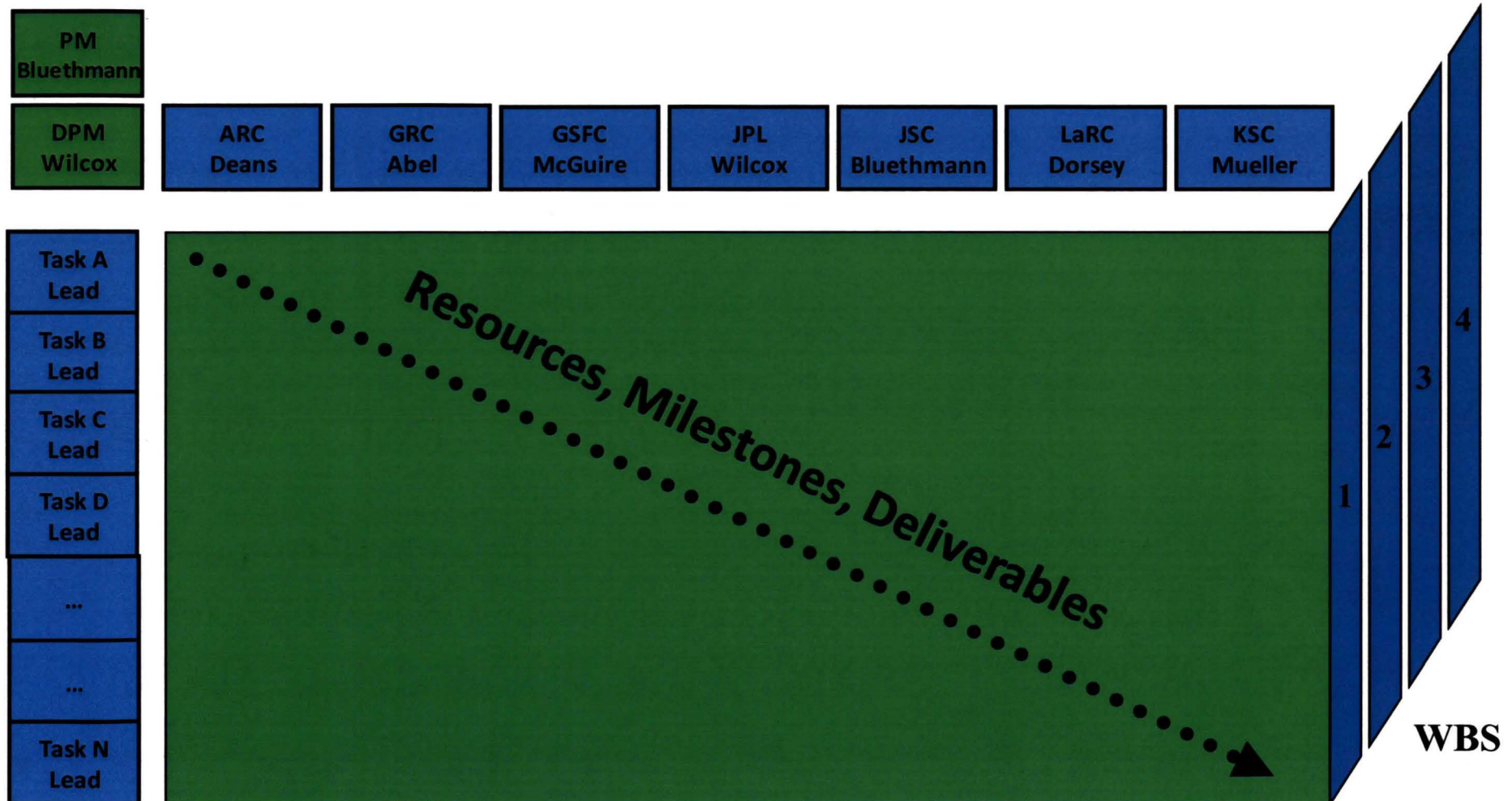
- HRS develops and matures prototype systems, subsystems, and component technologies in advance of key agency decision points
- Re-use existing robots though...
 - Improving functionality/fidelity of hardware and software
 - Using in new or novel ways
- Build selective new robots
- Be flexible in scope to meet needs of agency as (or before) they emerge

HRS Approach



- Work with human exploration architecture communities
 - Answer architecture questions being debated
 - Build machines that extend the thinking of the architecture community
- Leverage outside resources
 - Past HRS development
 - Other NASA development
 - Commercial partnerships
 - Space Act Agreements
 - Other agencies (DLR, CSA, JAXA, et.c.)
 - Small Business Innovative Research (SBIR) contracts
 - University research
 - National Robotics Initiative – USA White House

HRS Team Organization



FY12 Themes



- In-space work (Asteroid, ISS, HEO)
- EVA crew mobility
- Analog mission support
- Controlling robots through teleoperation or supervision
- Excavation
- Heterogeneous robot teams
- Basic robotics research

FY12 Task List



Task ID	Task Title	WBS	Lead Center	Task Lead	Support
2.0 Mobility					
2.1.1	Prototype next generation jetpack for flat floor testing	2.1 Free Flyers	JSC	Lewis	
2.1.2	Prototype ballistic sensor / payloads	2.1 Free Flyers	JSC	Bridgwater	JPL, ARC, GRC, KSC
2.1.3	Prototype Flyer/Rover Team for Lava Tube Exploration	2.1 Free Flyers	JSC	Goza	JPL, Army
2.3.1	Complete Low Gravity Testbed using tethered Stewart platform	2.3 Legs and Other Mechanisms	JPL	Wilcox	
2.3.2	Complete Active Response Gravity Offload System for suited crew	2.3 Legs and Other Mechanisms	JSC	Dungan	
2.4.1	Advanced mobility navigation software	2.4 Components, Controls and Analysis	ARC	Deans	
2.4.2	Test existing rover in lunar precursor scenario	2.4 Components, Controls and Analysis	JSC	Magruder	KSC
2.4.3	Test rover getting unstuck from soft soils	2.4 Components, Controls and Analysis	GRC	Abel	JSC, JPL
3.0 Handling					
3.1.1	Prototype grapple arm for Space Exploration Vehicle (SEV)	3.1 Large Scale Manipulation	JPL	Wilcox	JSC
3.1.2	Long reach manipulator, joint prototypes	3.1 Large Scale Manipulation	LaRC	Dorsey	JSC, JPL
3.1.3	Test Dynamic control of existing tensegrity structure	3.1 Large Scale Manipulation	ARC	SunSpiral	LaRC
3.2.2	Prototype dexterous sampling arm for SEV	3.2 Fine Manipulation	JSC	Diftler	
3.2.3	Tool Change-out interface umbilical integration	3.2 Fine Manipulation	KSC	Mueller	JSC
3.3.1	C2 volatiles Mining End Effector Development	3.3 Excavation	KSC	Mueller	GRC, JSC
3.3.2	Prototype excavator for Centaur 2	3.3 Excavation	GRC	Abel	KSC, JSC
3.3.3	Dozing mode of excavator on Centaur 2	3.3 Excavation	GRC	Abel	JSC
3.3.4	Test trenching using existing robots in mixed and icy regolith types	3.3 Excavation	KSC	Mueller	JPL
3.3.5	Prototype anchoring end effector for asteroid with sensors	3.3 Excavation	JPL	Wilcox	GRC, KSC, LaRC
4.0 Human Systems Interaction					
4.1.1	Test existing robot in lunar precursor level of tasks and communication	4.1 Supervising Robots over time delay	JSC	Hambuchen	ARC
4.1.2	Exploration Ground Data Systems development	4.1 Supervising Robots over time delay	ARC	Cohen	JPL, JSC
4.1.3	Providing a unified cross-center operations platform	4.1 Supervising Robots over time delay	JPL	Mittman	JSC, ARC
4.2.2	Natural user interfaces for advanced telerobotic operations	4.2 Teleoperating robotics in space	JPL	Norris	JSC
4.3.1	Prototype hands free control of EVA Jetpack	4.3 Working adjacent to robots in space	JSC	Rochlis-Zumb	JPL



HRS FY12 Continuation Review ARC

Matt Deans, Ph.D.

ARC Center Point of Contact

Task 2.4.1: Advanced Mobility Navigation Software

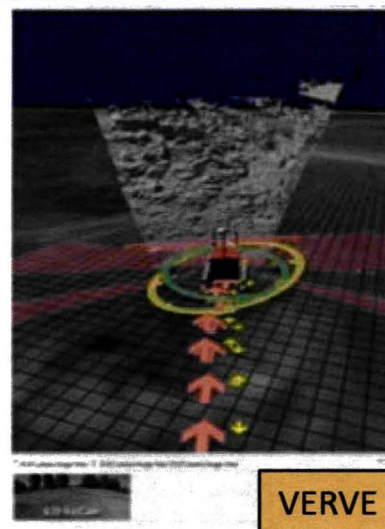


Task Lead: Matthew Deans (ARC)

Task Support: Bill Bluethmann (JSC)

Current status of work:

Extend and enhance past HRS work on onboard autonomous mobility, Dark Navigation, and hazard detection/display for high-speed crew mobility.



FY12 Task Description:

The Advanced Navigation Software task will develop approaches for dealing with significant challenges of autonomous planetary surface navigation, including:

- crater descent on rough and steep terrain
- exploring lava tubes
- navigating long distances without communications
- localizing without infrastructure using simultaneous localization and mapping (SLAM)

OCT Roadmap Linkage :

TA 4.5.3 Autonomous Guidance and Control
TA 4.1.3 Terrain mapping classification, & characterization
TA 4.1.4 Natural and man-made object recognition
TA 7.1.1 Destination reconn, prospecting and mapping
TA 7.3.2 Surface mobility

Milestones:

Feb 2012 Integrate navigation software/hardware on C2
Jun 2012 Test C2 driving long distance with limited comms
Sep 2012 Test lava tube exploration using K10
FY13 iterate mapping/navigation, more distance, less comm

Key Milestone – June 2012

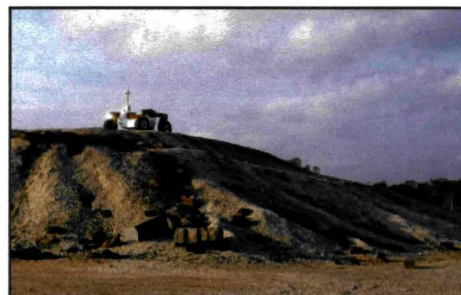
Task 2.4.1: Advanced Mobility Navigation Software



Objective: Operate Centaur 2 long distances with limited communications

Key Accomplishment:

- Demonstrated safeguarded teleoperation system
- Hardware, software, middleware, user interfaces
- Several kilometers, 25 cm/s, 1Mbps link
- Rocks, slopes and simulated lunar craters
- Two HRS rovers: Centaur 2 (JSC), KREX (ARC)



Centaur 2 in the JSC Rock Yard



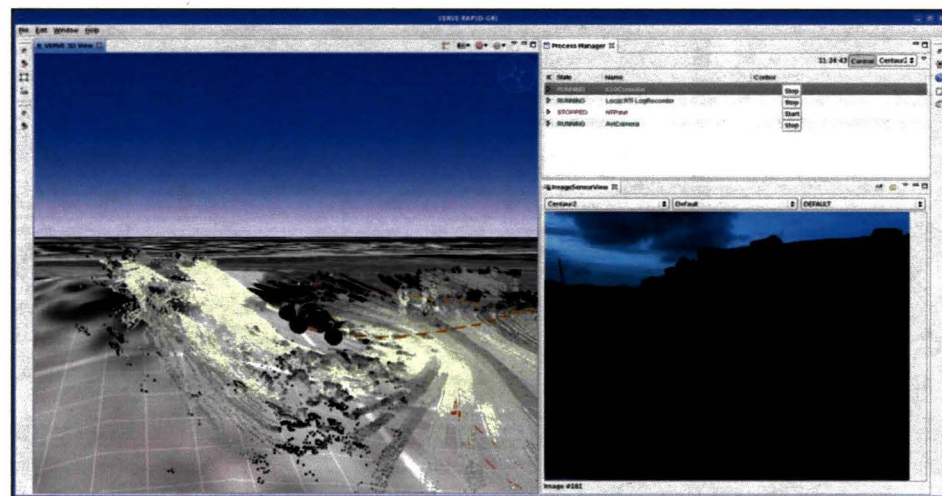
Hazard map in VERVE

Significance:

- Enables operating over time delays
- Enables strategic commanding
- Begins to allow Centaur 2 to make tactical choices

Additional information:

- Uses RAPID (HRS FY12 Task 4.1.3)
- Key products:
 - Sensor mast
 - Mapping, terrain analysis, hazard detection s/w
 - Operator displays
 - Onboard safeguarding
- Presented Plenary at iSAIRAS-2012

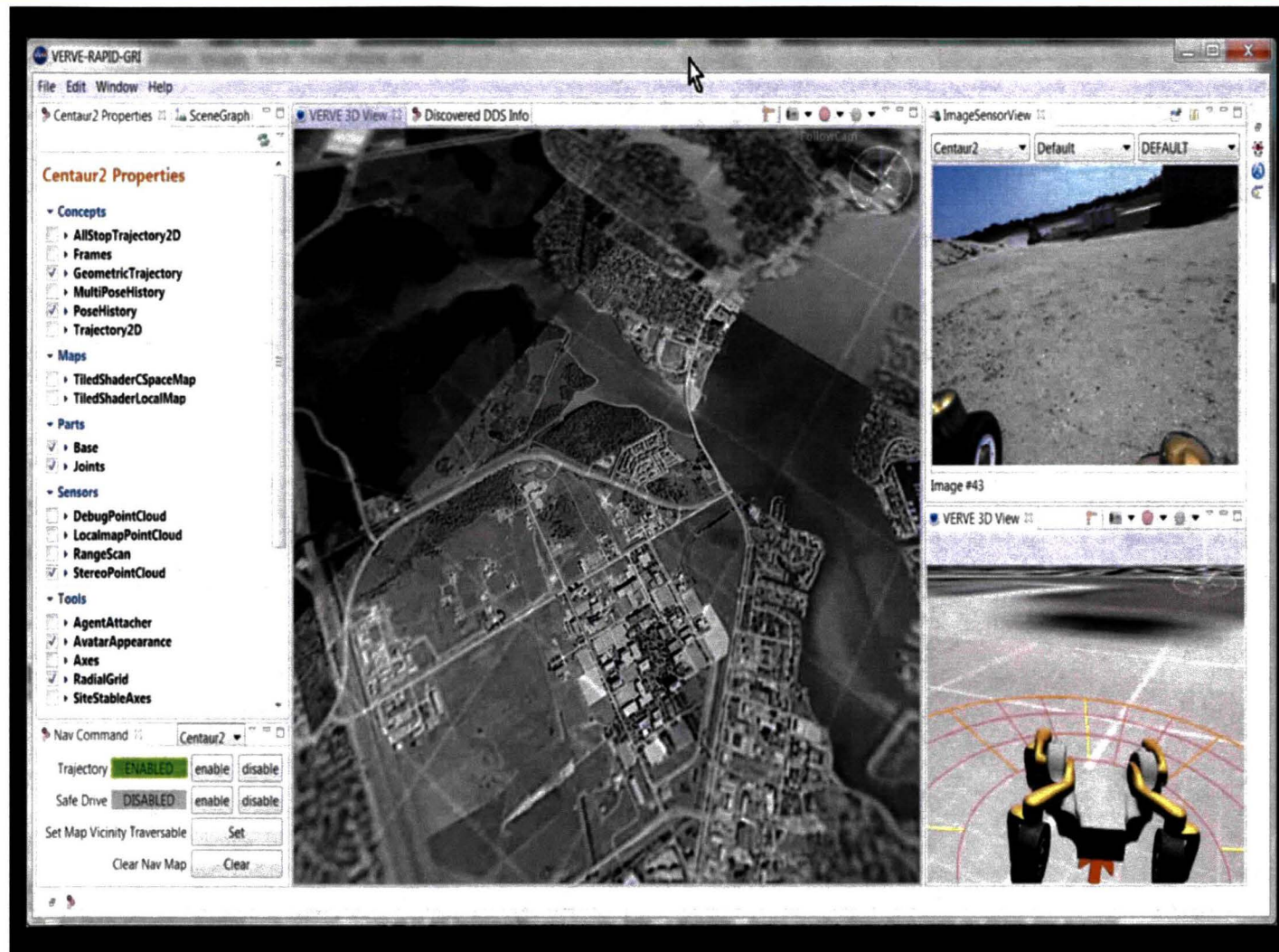


3D terrain and LIDAR view

Mast camera view

Testing – July 2012

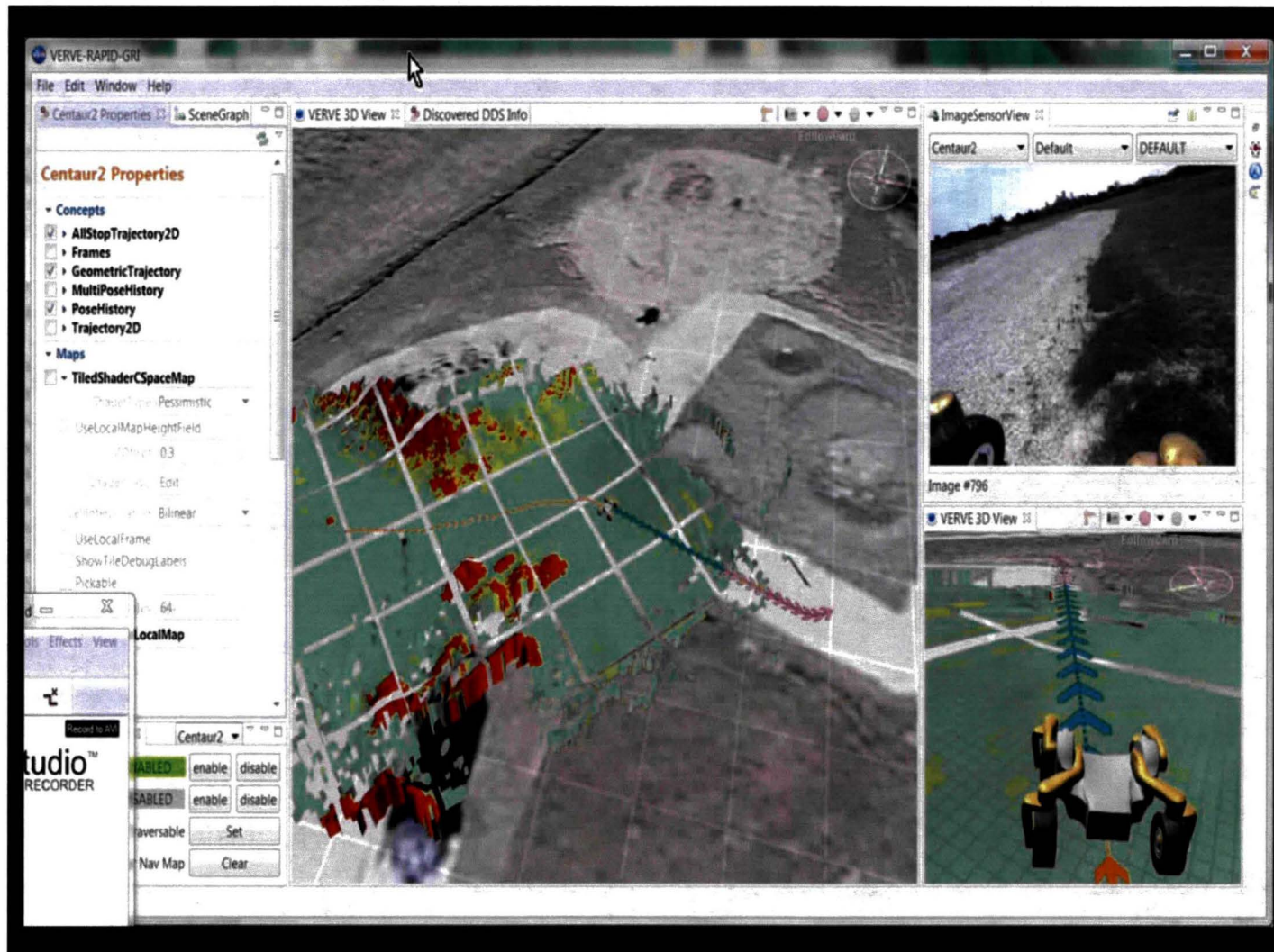
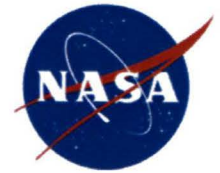
Task 2.4.1: Advanced Mobility Navigation Software



(Click image for video)

Testing – July 2012

Task 2.4.1: Advanced Mobility Navigation Software



(Click image for video)

Task 3.1.3:

Test Dynamical Control of Existing Tensegrity Structure

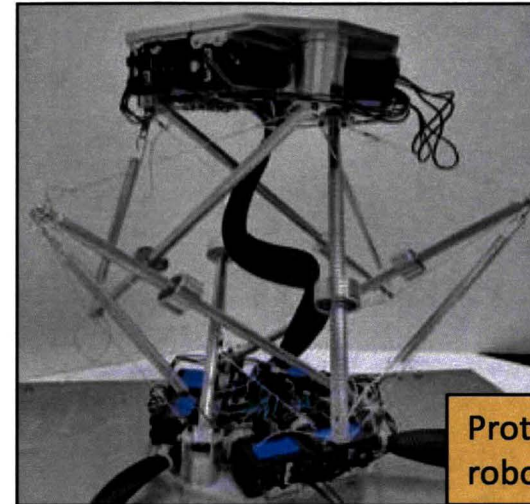


Task Lead: Vytas SunSpiral (ARC)

Task Support: John Dorsey (LaRC)

Current status of work:

This is a new task, which will utilize a prototype robot that was recently developed.



Prototype tensegrity robot (U. Idaho / ARC)

FY12 Task Description:

Tensegrity structures have potential for size, mass, and energy savings; are deployable from small volumes; and can be used for a variety of space applications.

- This pilot task will explore control of dynamic tensegrity structures. Control of these highly non-linear structures will make use of new ideas emerging from distributed control systems.
- This task will also explore novel forms of highly redundant superimposed tensegrity structures which can robustly support a wide range of structural motion with reliability through redundancy.

OCT Roadmap Linkage :

TA 4.3.1 Robot arms

TA 4.3.3 Modeling of contact dynamics

Milestones:

Jun 12: Demonstrate kinematic control of an existing prototype

Aug 12: Demonstrate distributed force control in a physics simulator

FY13: Evolve prototype for force control applications

Results – Kinematic Control (Jun) & Distributed Force Control (Aug)

Task 3.1.3: Test Dynamical Control of Existing Tensegrity Structure



Objectives: Demonstrate kinematic control of an existing prototype
Demonstrate distributed force control in a physics simulator

Key Accomplishments:

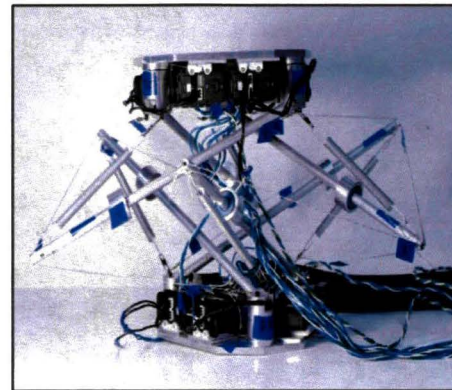
- Developed Generic FK/IK Algorithms for Tensegrity Robots and submitted for Journal Publication.
- Built physics based simulation environment for Tensegrity Robots to explore structure and control.
- Developed fully distributed impedance controller which produces robust coordinated behaviors.

Significance:

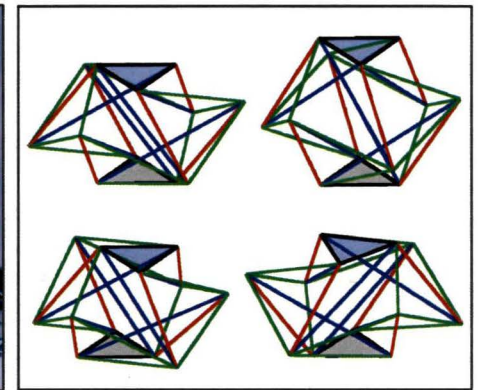
- Robust environmental interaction at level of structure and distributed control – simplifies control and planning, especially in cases of dynamic events (e.g. soil slippage, poor grasp quality, etc.)
- Distributed controls based on neurological CPG models which apply to manipulation and all forms of environmental interaction.

Additional information:

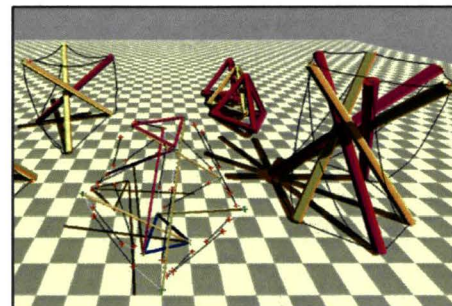
- Won NIAC grant
- Submitted Journal paper, writing 4 more papers.
- Collaborating on Army and DARPA BAA's.



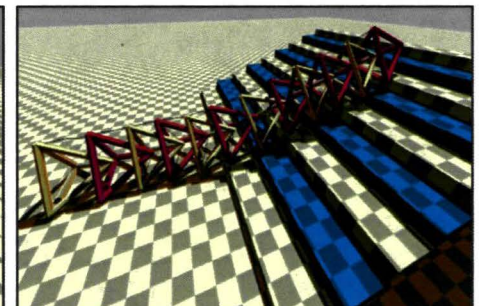
TenseBot testbed



Different IK solutions



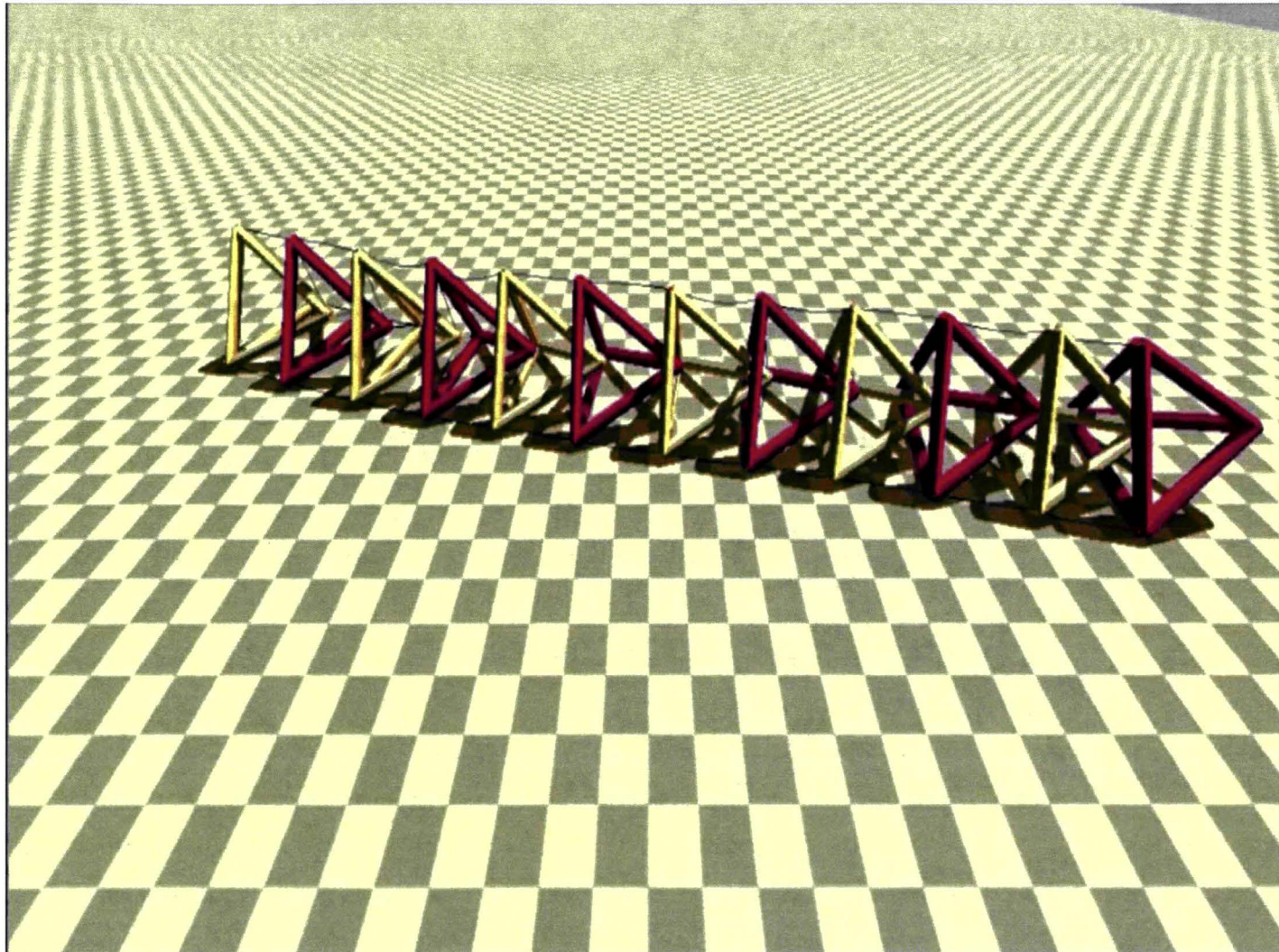
Tensegrity Simulator



Open loop distributed control can traverse complex terrain

Results – Distributed Force Control Simulator Test (Aug)

Task 3.1.3: Test Dynamical Control of Existing Tensegrity Structure



Robust environmental interactions, with no high level control or world model
(click image for video)

Task 4.1.2: Exploration Ground Data Systems (xGDS) Development

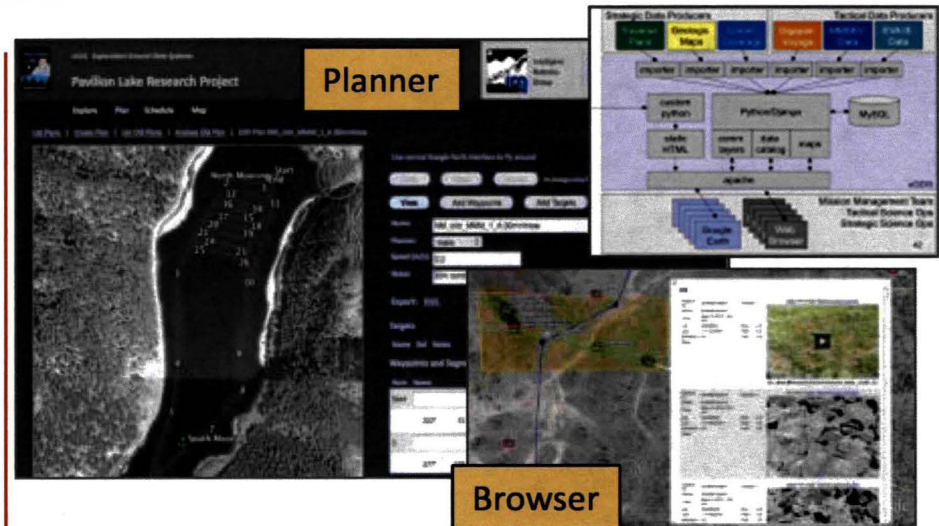


Task Lead: Tamar Cohen (ARC)
Task Support: Jodi Graf (JSC)
David Mittman (JPL)

Current status of work:

Continuation of FY11 task to develop prototype ground data systems tools.

These tools will support robot and crew vehicle science and operations, and to prepare systems for opportunistic testing at analog field sites.



FY12 Task Description:

Exploration Ground Data Systems (xGDS) is a set of planning, monitoring, archiving, and search tools for dealing with plans and data to and from robotic spacecraft or crew systems. xGDS uses web-based applications for portability and to support remote users. xGDS leverages open source web platforms, and open standards for maps and other file formats.

- In FY12, emphasis will be on reducing ops team size and enabling teams (ground and crew) to operate quickly and efficiently in high-tempo ops scenarios.

OCT Roadmap linkage :

- | | |
|----------|--|
| TA 4.1.3 | Terrain mapping, classification and characterization |
| TA 4.4.2 | Supervisory control |
| TA 4.4.5 | Distributed Collaboration |
| TA 4.4.6 | Common human-robot interfaces |
| TA 4.5.4 | Multi-agent coordination |

Milestones:

- Mar 12 Demonstrate high-tempo data analysis and planning with small ops team
- May 12 Test xGDS on Centaur 2 operations
- FY13/14 support of AES analog missions

Results – Centaur 2 test (May) & ISRU Field Test (July)

Task 4.1.2: Exploration Ground Data Systems (xGDS) Development



Objectives: Test xGDS on Centaur 2 operations
Demonstrate high-tempo data analysis and planning with small ops team

Key Accomplishments:

- Integrated xGDS Planner and VERVE/PIGI software
- Built a new plotting framework
- Built a new mapping framework
- Supported ISRU Field Test (AES funded)

Significance:

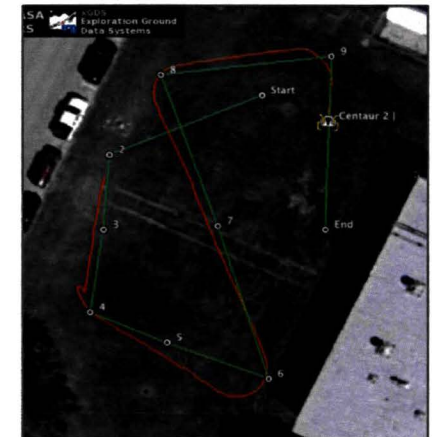
- Enables route planning for HRS robots
- Enables real time science decision support
- HRS transferred technology to an AES project

Additional information:

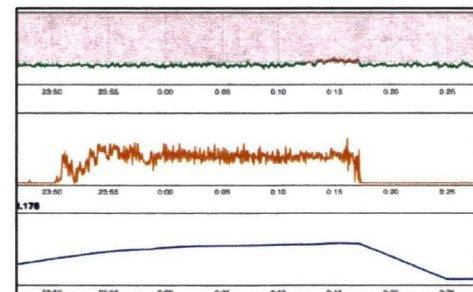
- Uses RAPID (HRS FY12 Task 4.1.3)
- Key products:
 - Core software for planning, plotting, mapping
 - Integration to RAPID telemetry
 - Designed to support many systems
- Very positive feedback from science and ops teams



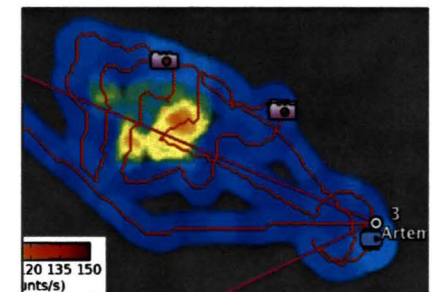
xGDS Planning



xGDS Tracking



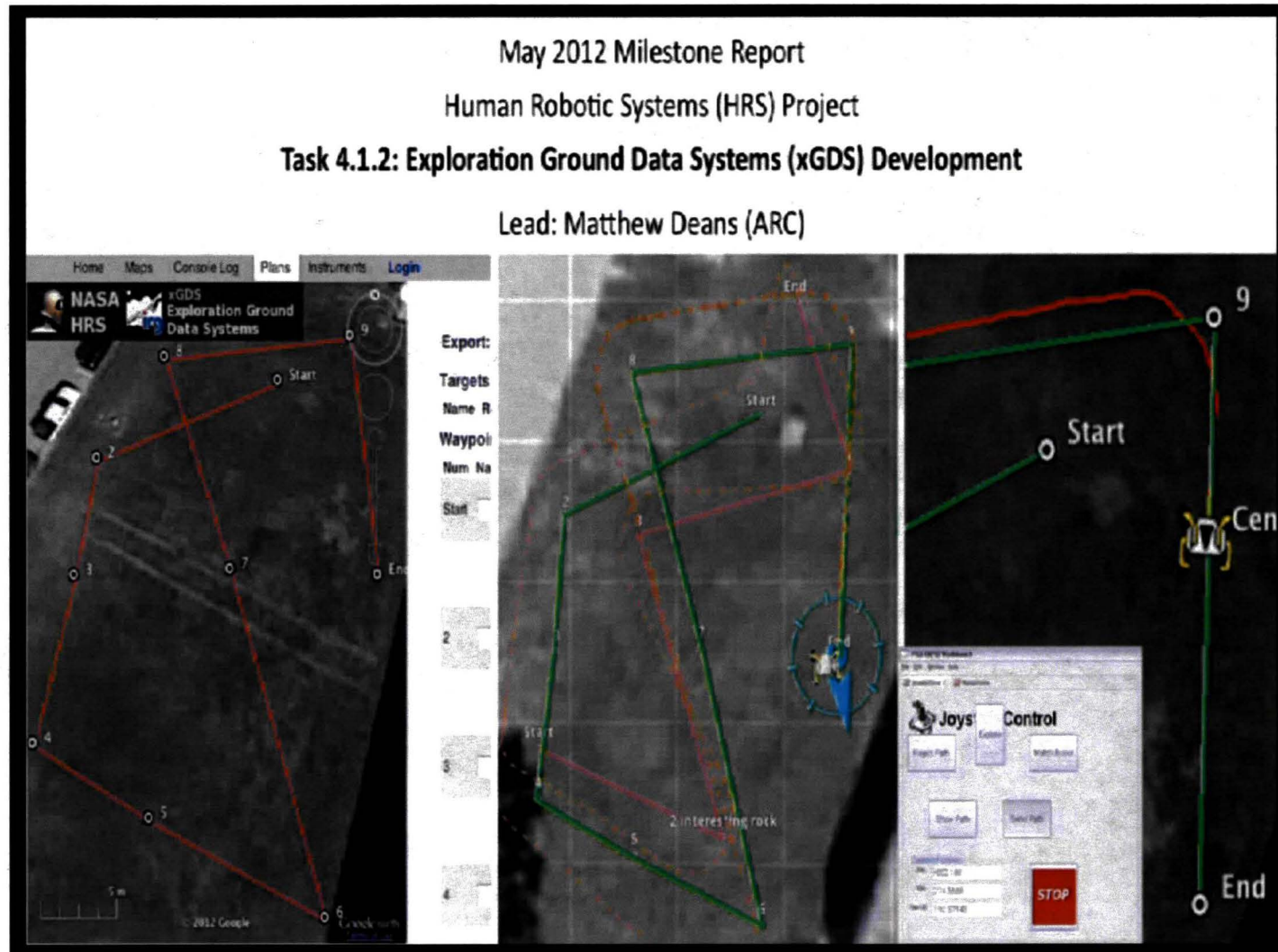
xGDS Plotting



xGDS Mapping

Key Milestone – May 2012

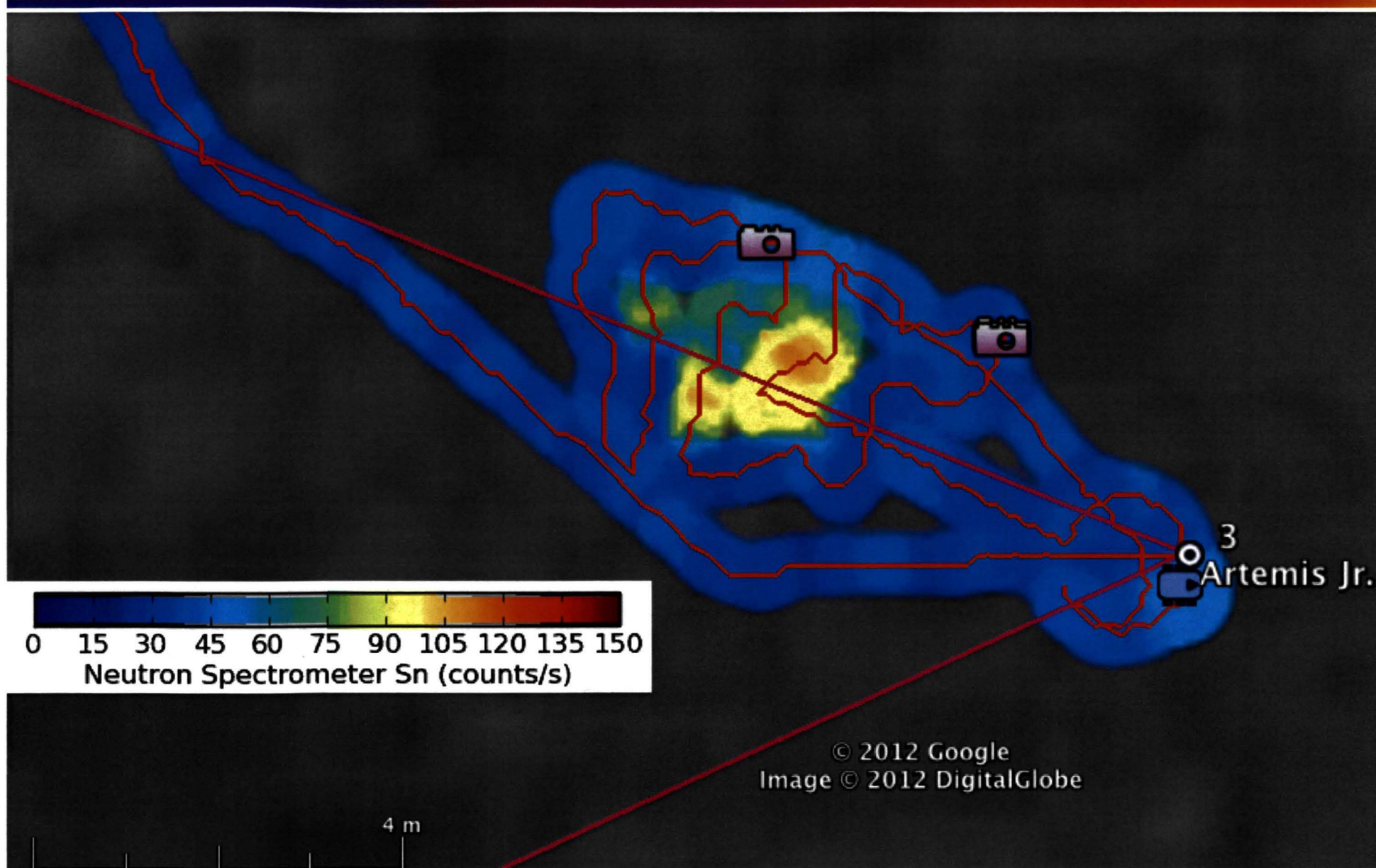
Task 4.1.2: Exploration Ground Data Systems (xGDS) Development



(click image for video)

Testing – July 2012 – xGDS Maps

Task 4.1.2: Exploration Ground Data Systems (xGDS) Development





HRS FY12 Continuation Review GRC

Phil Abel, Ph.D.

GRC Center Point of Contact

Task 2.4.3: Test Rover Extrication from Soft Soils



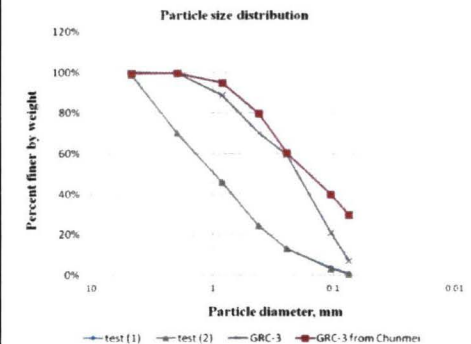
Objective: High sinkage simulant testing capabilities

Accomplishments:

- Graduate student evaluation of ultra-low mass alternative simulant materials - not selected
- Initial characterization of high-sinkage material
- Summer student project to build test platform using a single actuator, identical to Proteus motor / controller, with unidirectional wheel rotation
- Initial comparison of locomotion efficiency - Proteus and single actuator platform

Significance:

- Simulant decision verified
- Enable separation of traction effects



Task 2.4.3: Test Rover Extrication from Soft Soils



Task Lead: Phillip Abel (GRC)

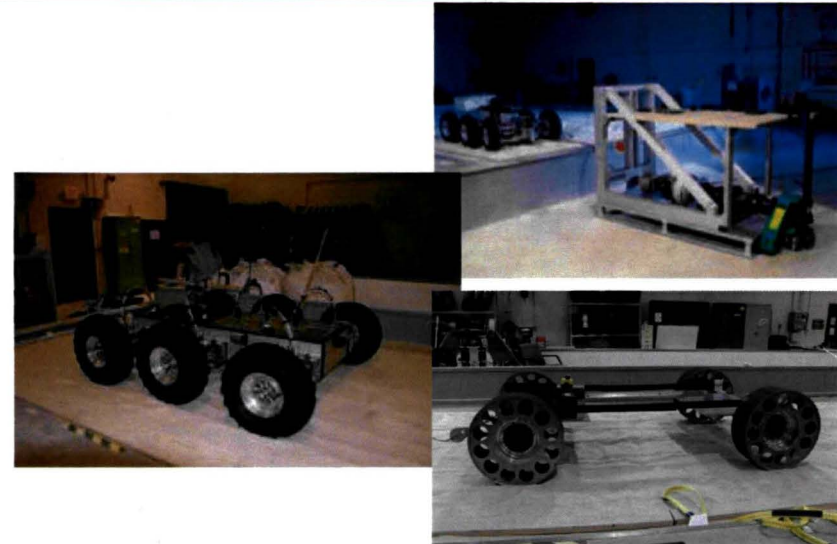
Task Support: JSC, JPL, CMU

Overview:

Negotiating treacherous, varying soil conditions is a facet of extreme terrain mobility to pursue, e.g. Spirit on Mars.

Current status of work:

- During FY12 graduate student research sifted through various analogs for low-gravity regolith. One side of the SLOPE laboratory soil bin has been provided with a high sinkage regolith analog.
- With enhanced modularity already incorporated, more power, higher speed, and improved steering accuracy and intelligence were added to the student-built tire / traction test-bed, Proteus.



Task Description:

- In FY13 this task will continue to use the student-rebuilt test-bed platform Proteus to investigate self-extrication in high sinkage soil and efficient travel mode comparisons.
- On-board sensors will be tested for automated control feedback, and traction force measurements using external sensors will be matched to internal sensing results.
- Single wheel testing feasibility will be evaluated using existing infrastructure (ISRU) & common hardware with mobile test-bed.
- Drawbar-pull rig will be upgraded to a more robust and portable configuration for field testing, e.g. also at JSC Rockyard or JPL.
- Photogrammetric system will be customized suitable for large field testing, such as at JSC Rockyard or JPL.

OCT Roadmap linkage:

- TA4.2.1 Extreme terrain mobility
- TA4.1.2 Relative Position & Velocity Estimation
- TA4.1.3 Terrain Mapping, Classification & Characterization
- TA4.5.1 Vehicle System Management & FDIR
- TA4.5.7 Path & Motion Planning with Uncertainty
- TA7.3.2 Surface mobility

Milestones:

- Oct 12: Enhanced vehicle sinkage measurements demo
- Apr 13: Report on self-extrication modes

Task 3.3.2:

Prototype Excavator for Centaur 2 - Exploring depths



Task Lead: Phillip Abel (GRC)

Task Support: Magruder(JSC), Mueller(KSC)

Current status of work:

- During FY11 an excavator for Centaur 2 based on a wide scoop bucket sized for ISRU was incorporated under the RAPID communications scheme via the Centaur 2 control software.
- The excavator has two degrees of freedom and a one-meter "reach", relying on the extreme mobility of Centaur 2 for lateral control and added "lift".



FY12 Task Description:

- Drawing upon FY11 excavator experience, and in collaboration with JSC and KSC, this task will produce an enhanced excavator for probing into soil depths.
- Using existing Centaur 2 interface knowledge, an articulated sampling excavator with greater reach and flexibility will be designed and built.
- The "working end" will feature a quick disconnect built in concert with KSC for an "impulse bucket" to lower excavation forces.
- Excavation forces in controlled soil with / without the bucket percussion will be measured in the SLOPE facility.

OCT Roadmap Linkage:

TA4.3.3 Modeling of contact dynamics

TA7.1.1 Destination reconn, prospecting and mapping

TA7.1.2 Resource acquisition

Milestones:

Mar 12 Initial prototype built

Jun 12 Excavator positioning mechanism assembled

Dec 13 Excavator/C2 testing JSC Rockyard demonstration

Task 3.3.3: Dozing Modes of Excavator on Centaur 2

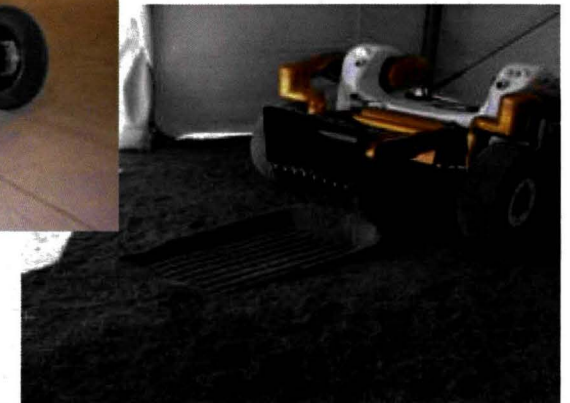


Task Lead: Phillip Abel (GRC)

Task Support: Magruder (JSC), Mueller (KSC)

Current status of work:

- During FY11 the excavation implement was more fully integrated into the Centaur 2 vehicle and controls.
- The RAPID protocol was supported via the vehicle intelligence and communications.
- Basic operation was demonstrated extensively at the Desert Research And Technology Studies exercise.



FY12 Task Description:

- In FY12 this task will further the implementation of autonomous control modes using excavator derived feedback while on Centaur 2.
- On-board sensor schemes will be investigated, and excavation forces will be measured by Centaur 2.
- Coordinated operation of Centaur 2 with the excavator via the RAPID interface will be further evaluated.
- Upgraded excavation algorithms should be derivable.

OCT Roadmap linkage:

- TA4.3.3 Modeling of contact dynamics
- TA4.3.5 Robotics drilling and sample processing
- TA7.1.1 Destination reconn, prospecting and mapping
- TA7.1.2 Resource acquisition

Milestones:

- | | |
|--------|---|
| Apr 12 | Demonstrate force-mode excavation or equivalent with Centaur 2 at JSC |
| May 12 | Spring tire traction comparison for Centaur 2 |

Human Robotic Systems: Level 2 Milestone

Demonstrate force-mode excavation



Objective:

HRS Task 3.3.3: Dozing Modes of Excavator on Centaur 2

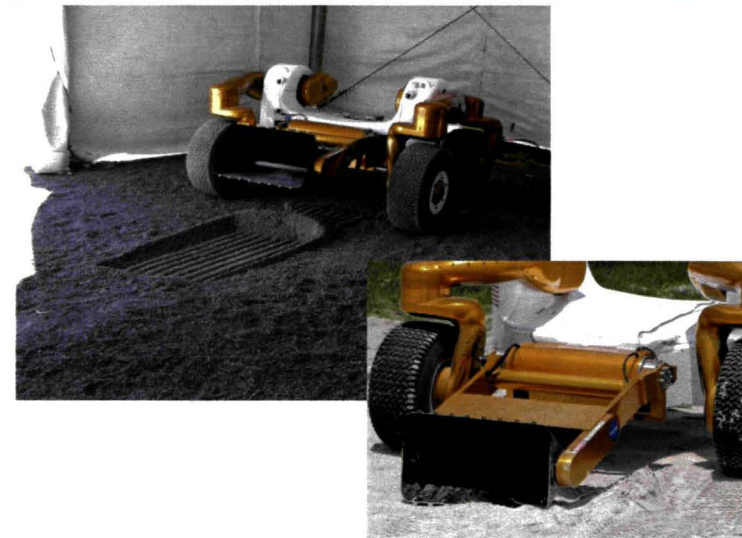
HRS milestone: Demonstrate force-mode excavation with Centaur 2 at JSC

Additional information:

During June, HRS engineers from GRC and JSC worked to demonstrate force-sensing autonomous operation of an excavation bucket on the Centaur 2 base in various types of soil. This task is developing additional autonomous modes using excavator derived feedback for bucket positional control to allow more efficient non-intervention operations.

Significance:

Combining scoop force and "fill-state" sensing with single operator vehicle control allows greater operational efficiency.



Human Robotic Systems: Milestone Update

Spring Tire Traction Comparison



Objective:

HRS milestone: Spring tire traction comparison for Centaur 2

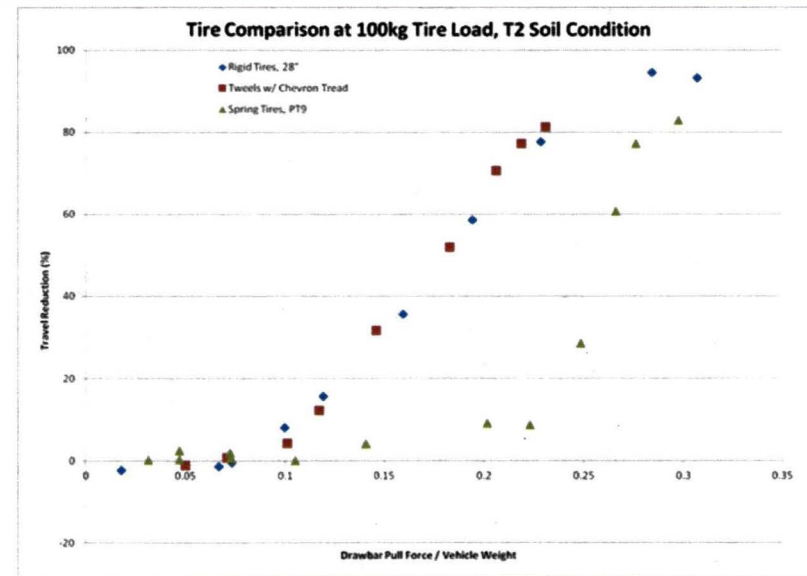
Patented Spring Tire was tested for traction performance in the SLOPE laboratory

Additional Information:

Using SLOPE laboratory measurement capabilities, drawbar pull performance of the NASA / Goodyear patented spring tire design was captured as a function of travel reduction (similar to wheel slip), and favorably compared to similarly sized wheels. Drawbar pull, or traction, normalized to vehicle weight indicates how much net force the tire can generate, which can be used to predict how well that tire will allow the vehicle to perform "in the field" such as climbing back out of a crater. This tire is made from helical springs interlaced with one another, thereby forming a toroidal structure extending around the entire circumference, giving high load bearing, compliance, and toughness.

Significance:

A non-pneumatic, vacuum compatible, performance tire enables greater range and terrain accessibility.



Task 3.3.2:

Prototype Excavator for Centaur 2 - Exploring depths



Task Lead: Phillip Abel (GRC)

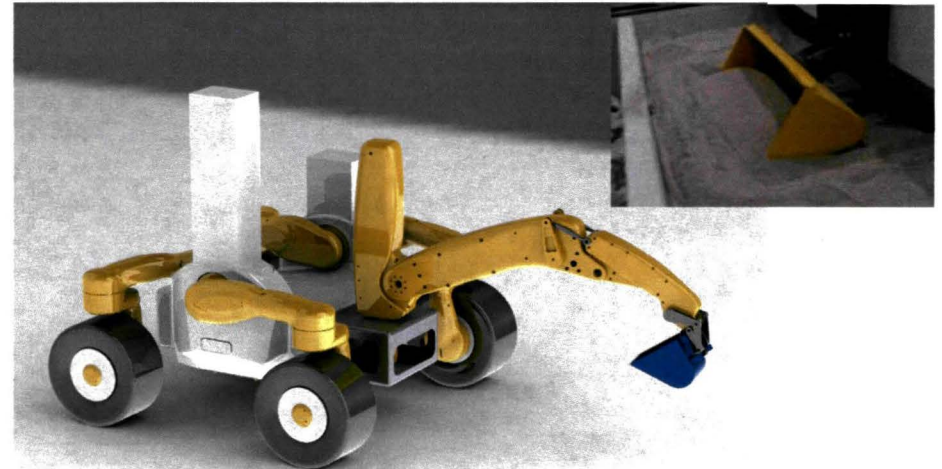
Task Support: Magruder(JSC), Mueller(KSC)

Overview:

A compact, robust and capable analog excavator provides experience with (remote) operations / autonomy.

Current status of work:

- During FY12 an excavator for Centaur 2 based on a wide scoop bucket, sized for ISRU, was semi-automated for ease of use via the Centaur 2 control software.
- Drawing upon FY12 excavator experience, and in collaboration with JSC and KSC, an articulated sampling attachment with greater reach and flexibility is being designed and built.



Task Description:

- In FY13 design, construction, and initial documentation of the enhanced excavator will be completed.
- Excavation forces in controlled soil, with and without bucket percussion, will be measured in the SLOPE lab.
- Ease-of-efficient-use algorithms for semi-autonomous excavation will be explored, in conjunction with RAPID integration issues.
- The "working end" quick disconnect feature, developed with KSC for an "impulse bucket" to lower excavation forces, will be investigated for enhanced functionality.

OCT Roadmap Linkage:

TA4.3.2 Dexterous Manipulators

TA4.3.3 Modeling of Contact Dynamics

TA4.3.4 Mobile Manipulation

TA7.1.1 Destination Reconnoiter, Prospecting & Mapping

TA7.1.2 Resource Acquisition

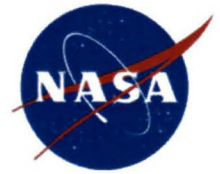
Milestones:

June 2013 Excavator positioning mechanism completed

Sept 2013 Quantify reaction forces at vehicle of excavation modes

Q1 FY14 Excavator/C2 testing JSC Rockyard demonstration

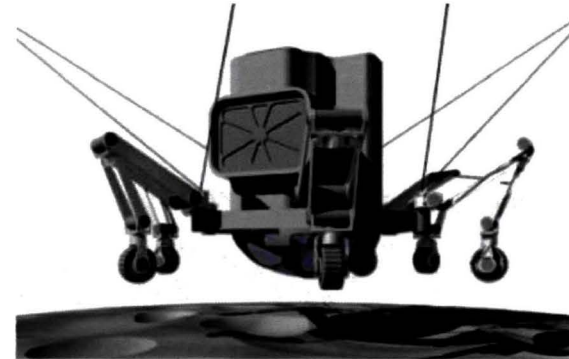
Task 2.3.1: Complete Low Gravity Testbed using Tethered Stewart Platform



Task Lead: Brian Wilcox (JPL)

Current status of work:

- Gantry frame has been installed into high-bay at JPL, with six computer-controlled winches and control system.
- 7x7 meter asteroid surface mockup procured from Hollywood set.



FY12 Task Description:

- Proximity and surface contact operations are simulated for asteroid or other low-gravity situations by suspending terrestrial prototype hardware from six computer-controlled winch cables, giving 6-DOF control over a ~3 m workspace.
- “Real” sensor feedback in terms of imagery, ranging, and contact sensing using accurate force sensors allows simulation of approach, landing, anchoring, release and departure statics and dynamics for near-Earth asteroid missions as well as 1/6th or 3/8th gravity simulations on extreme terrain without risking the hardware.
- “Simulations are doomed to succeed” is an adage in robotics, meaning that failure to incorporate hardware-in-the-loop sensing, particularly force sensing of contact, makes simulations of very limited value.

OCT Roadmap areas:

- 4.1.1 3D perception
- 4.1.2 Rel pos/vel estimation
- 4.1.5 Sensor fusion for sampling and manipulation
- 4.2.4 Small body/microgravity mobility
- 4.5.7 Planning with Uncertainty
- 4.6.1 Relative Navigation Sensors
- 4.6.2 Relative guidance algorithms

Milestones:

- Feb '12: 6-DOF “Free Flying” microgravity simulation with attitude control
(Met 2/23/2012)
- Jul'12: Force reactive microgravity simulation with force sensors integrated.
(Met 7/26/2012)
- Sep'12: Full 6-DOF proximity operations and landing simulation of NEA mission. **(Met 9/16/2012)**
- Mar'13: Demonstrate force controlled auguring using first generation un-instrumented auger-anchor
- Sep'13: Extend full proximity operations low gravity simulation to include anchoring and release in very soft regolith
- FY'14: Perform extreme-terrain steep-slope climbing in simulated 1/6th and 3/8th -gravity, with anchoring and release.

Feb '12: 6-DOF “Free Flying” microgravity simulation with attitude control (Met 2/23/2012)



The ATHLETE low gravity testbed and proximity operations simulation continues to progress with the integration of a more sophisticated physics simulation. This was successfully demonstrated this week with a simulated flight. This simulation included ‘flights’ with attitude control and a simulated flight in both zero g and micro gravity.

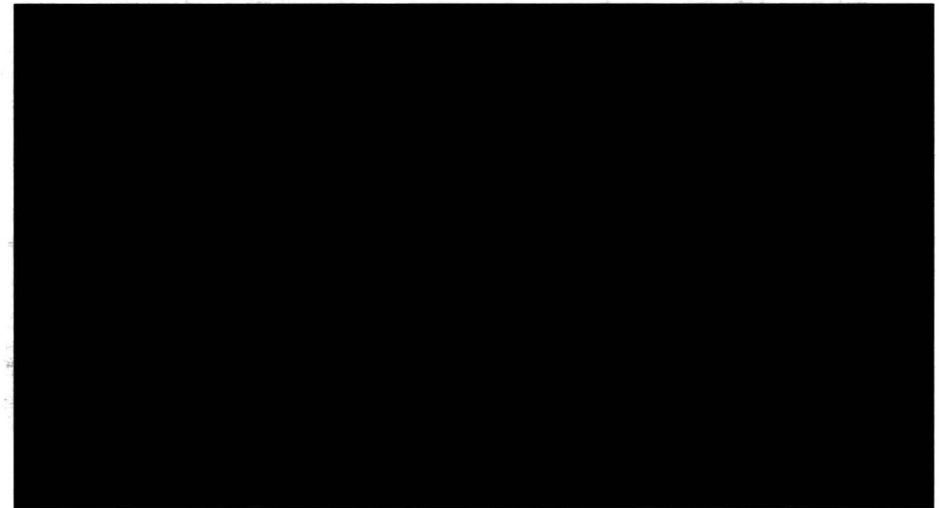


[Click image for video](#)

Jul'12: Force reactive microgravity simulation with force sensors integrated. (Met 7/26/2012)

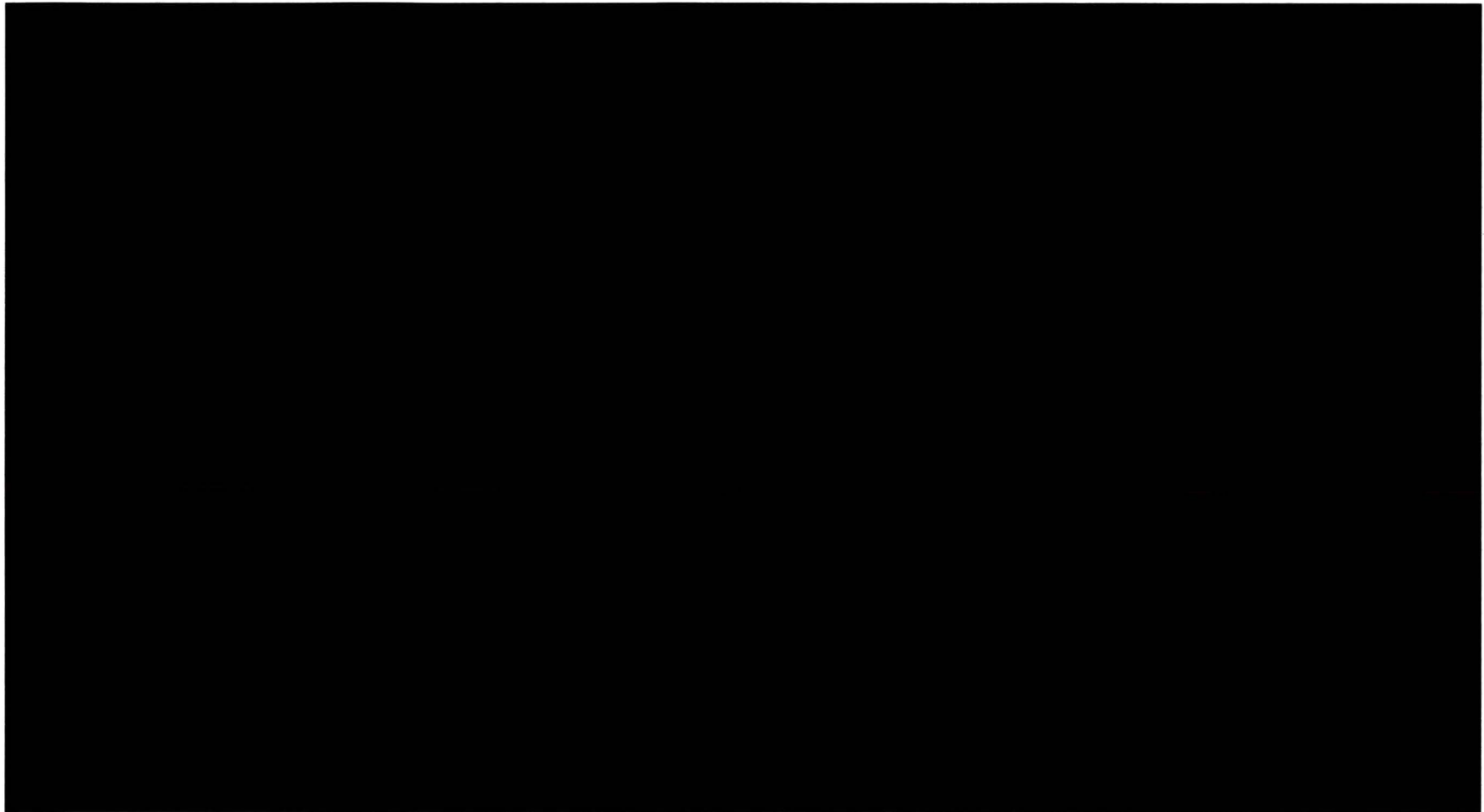


This simulation integrates the force sensors in the ankles to the low gravity simulation. The video shows the result -- a micro gravity bounce in a 0.005 m/s^2 gravity field. Testing is ongoing as the simulation is refined and we progress toward our full proximity operations simulation in September.



Click image for video

Sep'12: Full 6-DOF proximity operations and landing simulation of NEA mission.

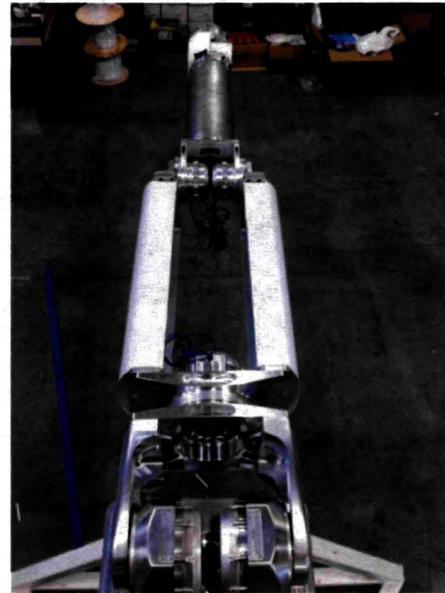


Click image for video

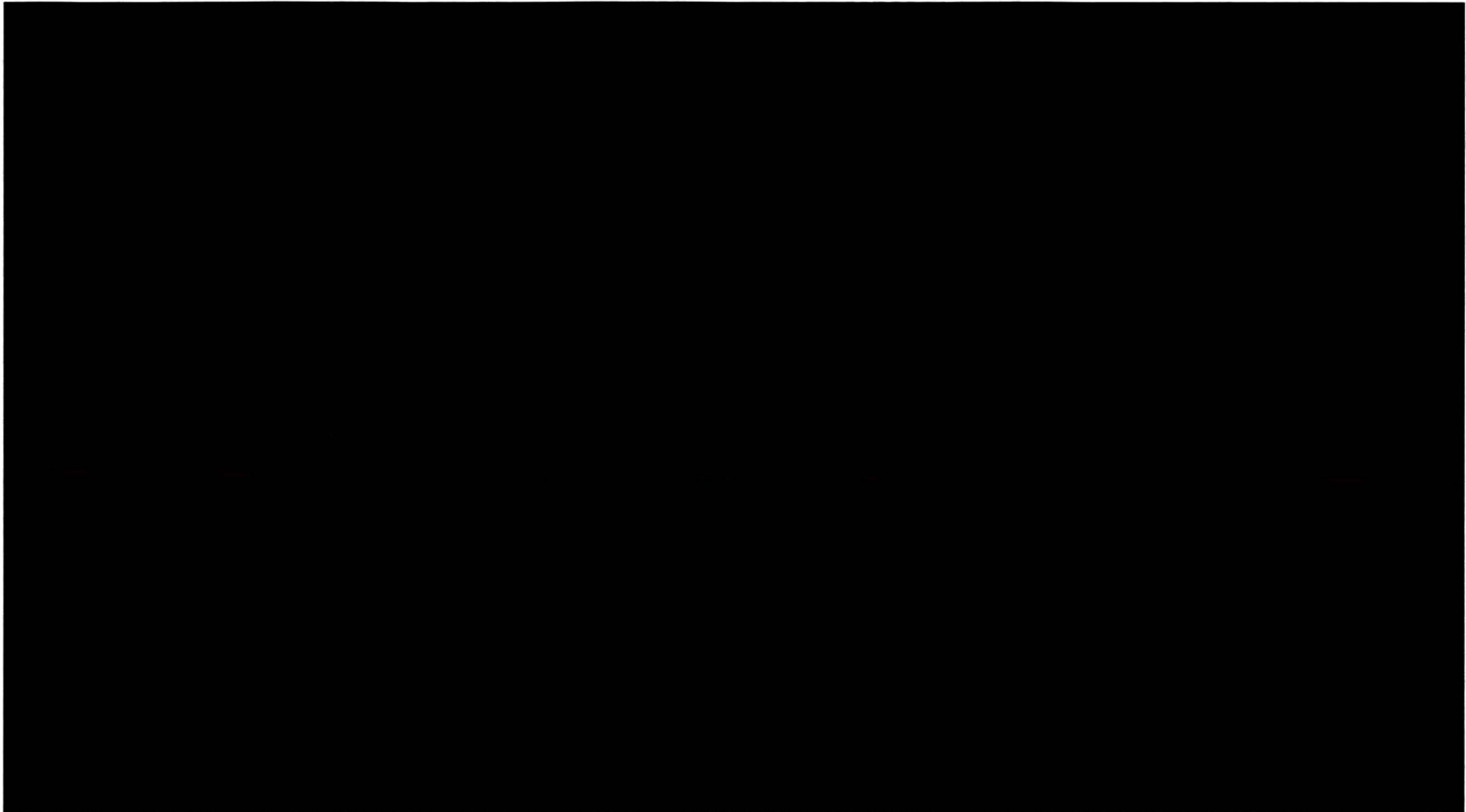
Jun'12: First prototype grapple arm assembled. (Met 6/29/2012)



Here are photos of the fully-assembled grappling arm destined for the MMSEV, fulfilling our milestone that is due by the end of June. As you know, this arm is about 3 meters long, and has a shoulder torque rating of 14000 Newton-meters.



Sep'12: Grapple arm tested at JPL



Click image for video



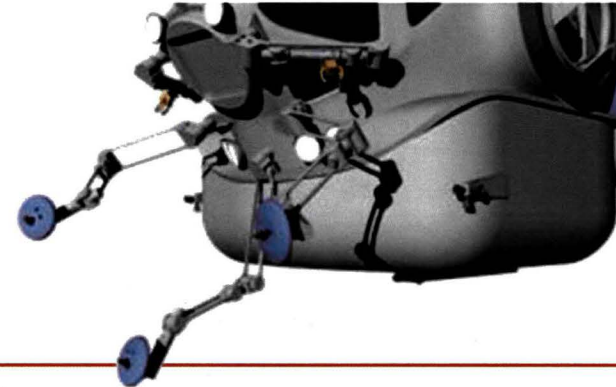
Task 3.1.1: Prototype Grapple Arm for Space Exploration Vehicle (SEV)

Task Lead: Brian Wilcox (JPL)

Task Support: Bill Bluethmann (JSC)

Current status of work:

An initial prototype grapple arm for the MMSEV was created in FY'12.



FY13 Task Description:

- Human missions to Near Earth Asteroids (NEAs) in particular require that up-close human exploration vehicles be able to safely make contact with and investigate the NEA surfaces.
- That requires grapple arms that can decelerate the vehicle from final approach velocities and make secure attachment in preparation for sampling or dexterous manipulation.
- Arms capable of providing stable attachment for the SEV to asteroids or to human artifacts not having special grapple fixtures will allow the SEV to perform scientific investigation or dexterous manipulation with other implements and arms suited for that purpose.
- This task will prototype, test and evaluate grapple arms with assorted anchoring and grasping implements using various simulated asteroid surface materials and using the 6-DOF Stewart platform developed under Task 2.3.1.
- Low-force rotary-percussive anchor for hard-rock will be prototyped and tested.

OCT Roadmap areas:

- TA4.1.5 Sensor fusion for sampling and manipulation
- TA4.2.4 Small body/microgravity mobility
- TA4.3.1.1 Robot arms
- TA4.3.4 Mobile Manipulation
- TA4.3.6 Robotic drilling and sample processing
- TA4.4.1 Multi-modal human-system interaction
- TA4.4.7 Safety, trust and interfacing of robotic/human proximity ops
- TA4.6.3 Docking and capture mechanisms/interfaces

Milestones:

- Jul'13: Begin using grapple arm in conjunction with anchoring device for soft regolith
- Sep'13: Prototype anchoring device for hard rock (e.g. percussive drill with expanding anchor) and test in range of hard rock surfaces at JPL.
- Sep'13: Deliver prototype grapple arm to JSC. (ACTUAL DELIVERY TBD)
- FY'14: Add grasping fixture for grapple human artifacts to stabilize SEV, and test in variety of assembly/maintenance/repair scenarios.

Task 3.3.5: Prototype Anchoring End Effector with Sensors for Asteroid

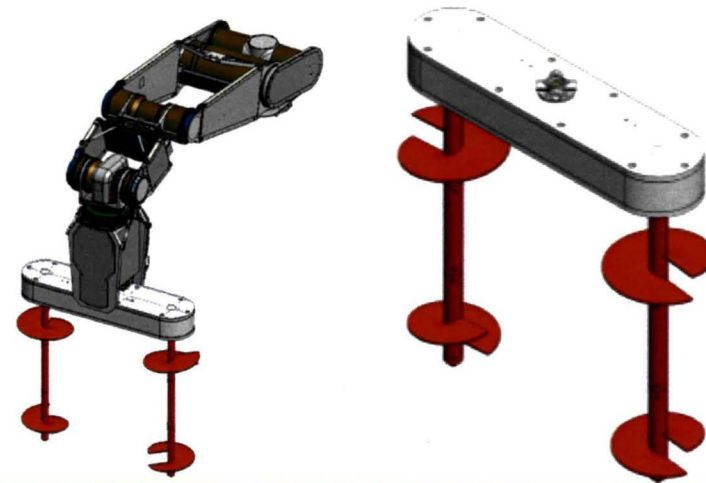


Task Lead: Brian Wilcox

Task Support: GRC (Abel),
KSC (Mueller),
LaRC (Dorsey)

Current status of work:

1st prototype of an emplaceable/releasable/reusable anchor for soft regolith has been designed and is in fabrication.



FY12 Task Description:

- Emplaceable/releasable/ reusable anchors can serve human exploration by providing endpoints for safety tethers allowing human explorers to maneuver over the surface of a NEA as with a “zip line”.
- Sensors embedded in the anchor could include acoustic/seismic emitters and receivers so that the array of anchors, perhaps emplaced by a fly-ahead robot that arrives several weeks ahead of the human crew, can perform internal tomography of the NEA.
- Human exploration of NEAs would be facilitated by emplacement of an array of anchors (preferable ahead of crew arrival) and knowledge of the internal structure of the NEA (especially knowledge that the configuration is not a gravitationally-unstable rubble-pile).

OCT Roadmap Areas:

- TA4.2.4 Small body/microgravity mobility
- TA4.3.3 Modeling of contact dynamics
- TA4.4.4 Common Human-systems interfaces
- TA4.5.5 Adjustable autonomy
- TA4.5.7 Path and motion planning with uncertainty

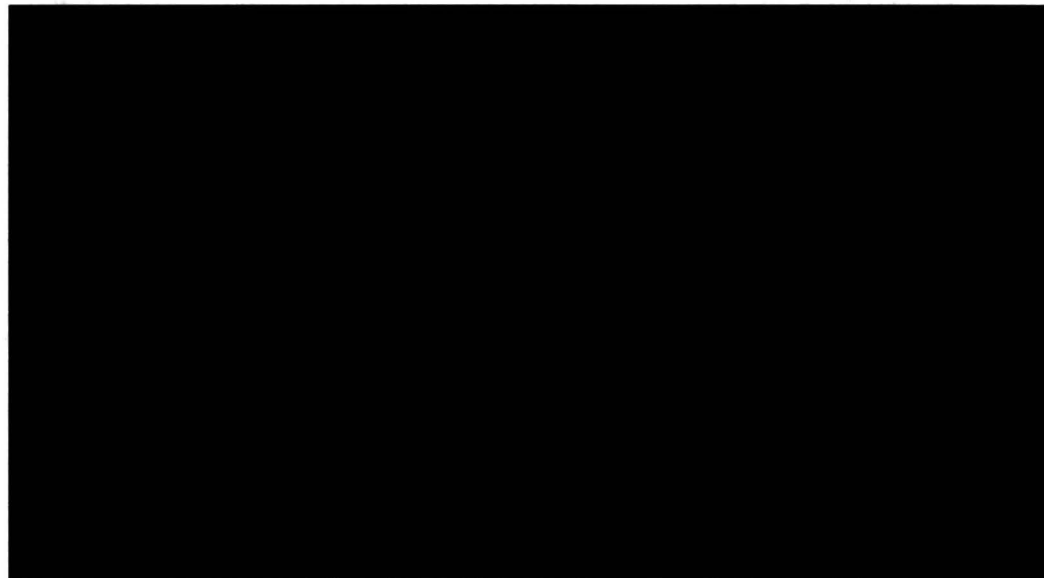
Milestones

- Mar’13: Design review of sensor pod integration into soft regolith anchor tool with battery powered thumper and geophone
- Jul’13: Prototype instrumented soft regolith anchor.
- Sep’13: Test releasable/reusable anchor for soft regolith with battery-powered “thumper” and geophone at JPL.
- FY’14: Prototype and test releasable/reusable anchor for both soft and hard surfaces, with thumper and geophone

Regolith Anchor



- Dual Counter-Rotating Augers react torque from each other, transmitting no net torque across tool interface
- Contact made with Caltech “Community Seismic Network”, who have placed thousands of low-cost seismometers in homes to map the geologic structures under Pasadena, CA.



Click image for video



Human Systems Interaction: FY12 Tasks & Results

September 19, 2012

David Mittman

Supervisor, Planning and Execution Software Systems Group

(818) 393-8232 FAX (818) 393-5074

David.S.Mittman@jpl.nasa.gov



Providing a Unified Cross-Center Operations Platform

Task Lead: David Mittman (JPL)
Task Support: Kim Hambuchen (JSC)
Hans Utz (ARC)

Status of Work: The RAPID* system for collaborative telerobotics includes SEV, Centaur 2, Robonaut 2, ATHLETE, K10, LSMS, EVAIS and EXARM; has been field tested over several years; works over NEO-class time delays; and supports transfer of large data sets through an asynchronous file transfer service. The RAPID collaboration has expanded to new NASA (GRC) and international Agency (ESA) relationships and is contributing to the development of international standards in telerobotics operations to enable NASA missions.

* Robot Application Programming Interface Delegate

Task Description: Develop and test improvements to the RAPID system of common telerobotic monitoring and control messages and services. Develop operations technologies and processes for safe coordinated operations of humans and robotic systems. The RAPID monitoring and control protocol will be extended to deliver commands and telemetry data more reliably over the multi-hop, unreliable networks that are common in both field testing and in space operations.



TABS Elements:

- Distributed Collaboration (TA 4.4.3)
- Multi Agent Coordination (TA 4.4.4)
- Common Human-Robot Interfaces (TA 4.7.8)

Milestones:

- Mar 2012: Test reliable data transport over DTN in the JPL laboratory setting.
- Sep 2012: Test reliable data transport between JPL, ARC and JSC using DTN and time delay technologies.



Providing a Unified Cross-Center Operations Platform

Milestone: Test reliable data transport over DTN in the JPL laboratory setting. (March 2012)

• Key Accomplishments

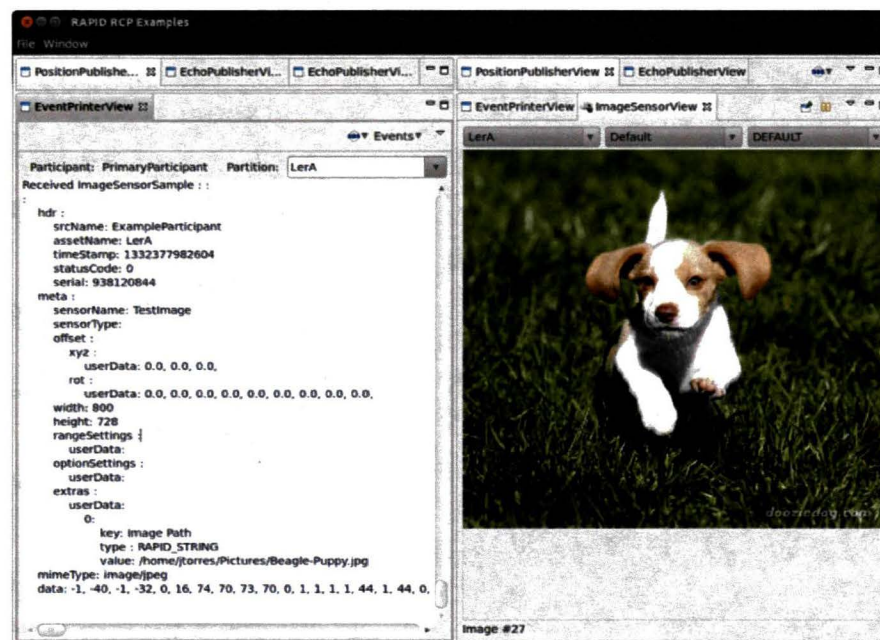
- Integrated the Robot Application Programming Interface Delegate (RAPID) on an IP over Delay-Tolerant Networking (DTN) stack (BPTAP)
- Demonstrated RAPID over DTN in the JPL Communications Laboratory

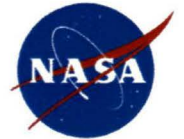
• Significance

- Validates multi-stack compatibility of RAPID
- Enables telerobotics operation over delay- and disruption-prone communications networks
- Adds robustness to RAPID-based telerobotics operations in the field, between centers and over space links

• Additional Information

- Abstract accepted at IEEE Aerospace 2013: "Deploying the Robot Application Programming Interface Delegate via Second-Generation IP-over-DTN"





Providing a Unified Cross-Center Operations Platform

Milestone: Test reliable data transport between Centers using DTN and time delay technologies. (September 2012)

- **Key Accomplishments**

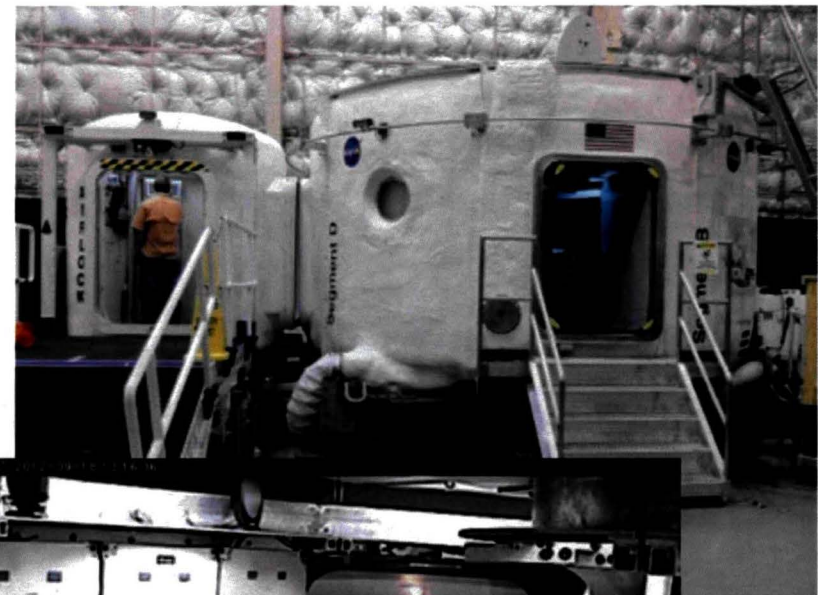
- Test date September 24, 2012

- **Significance**

- Will complete required network infrastructure for inter-Center and international collaborative operations in relevant end-to-end environment
- Infused telerobotics workstation design experience into AES Habitation Systems Deep Space Habitat

- **Additional Information**

- RAPID approved for public release under NASA Open Source Agreement Version 1.3
- Hosted at SourceForge and available at <http://rapid.nasa.gov>
- RAPID Version 2 to be released under the Apache License, Version 2.0 in CY12.





Natural User Interfaces for Advanced Telerobotic Operations

Task Lead: Jeff Norris (JPL)

Task Support: Sharon Goza (JSC)

Status of Work: Effectively controlling a high degree-of-freedom robot is a challenging and often safety-critical task. As these systems approach human-like dexterity, the body of the operator becomes the most natural and effective control device. In addition, accurate tracking of the operator's pose enables the rendering of a more immersive virtual representation of the robot's environment. We have demonstrated and tested several natural user interfaces for manipulation task control for R2 (JSC) and ATHLETE (JPL).

Task Description: This task will use body-tracking input devices (i.e. Microsoft Xbox Kinect and accelerometer gloves) to immerse an operator in an accurate virtual model of the robot's environment, capture the intent of the operator, and safely execute mobility and manipulation tasks suitable for platforms such as Robonaut 2 and SEV.

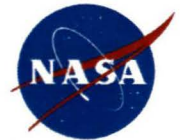


TABS Elements:

- Human-Systems Integration (TA 4.4)
- Immersive Visualization (TA 4.4.2)
- Remote Mission Operations (TA 7.5.3)

Milestones:

- Mar 2012: Model-based recognition of operator goals for robot pose
- Sep 2012: Demonstration of basic manipulation task control



Natural User Interfaces for Advanced Telerobotic Operations

Milestone: Model-based recognition of operator goals for robot pose. (March 2012)

- **Key Accomplishments**

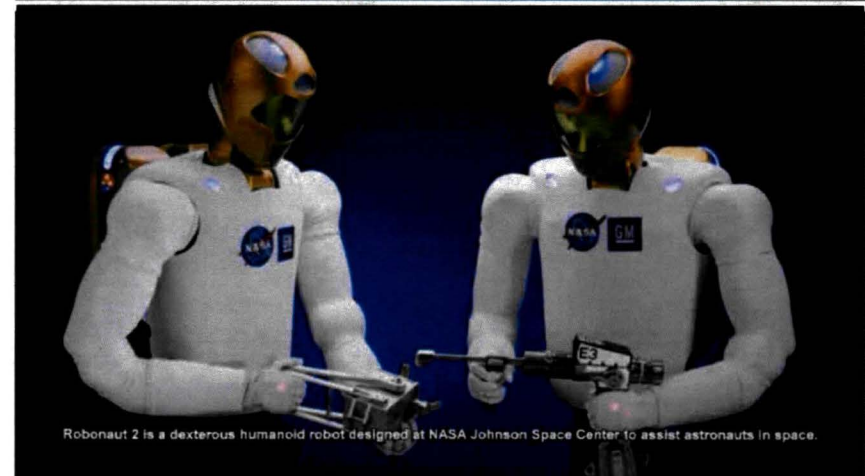
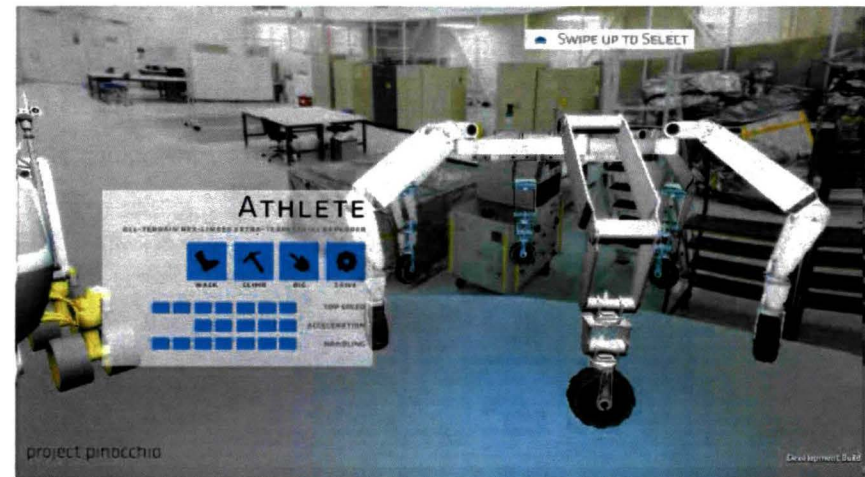
- Demonstrated controller-less technology for designating robot poses based on system-level robot models
- Developed 2.5D projection techniques, and head and hand tracking technology that frees the operator from the need to wear special eyewear, headgear, gloves or other devices

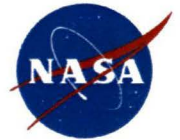
- **Significance**

- Operator experience transfers across robot types, reducing training requirements
- Natural user interfaces reduce cognitive load when operating non-anthropomorphic robots

- **Additional Information**

- Basic technology used in a wide variety of R2-based EPO efforts
- Abstract submitted for ACM SIGCHI Conference on Human Factors in Computing Systems, 2013





Natural User Interfaces for Advanced Telerobotic Operations

Milestone: Demonstration of basic manipulation task control. (September 2012)

- **Key Accomplishments**

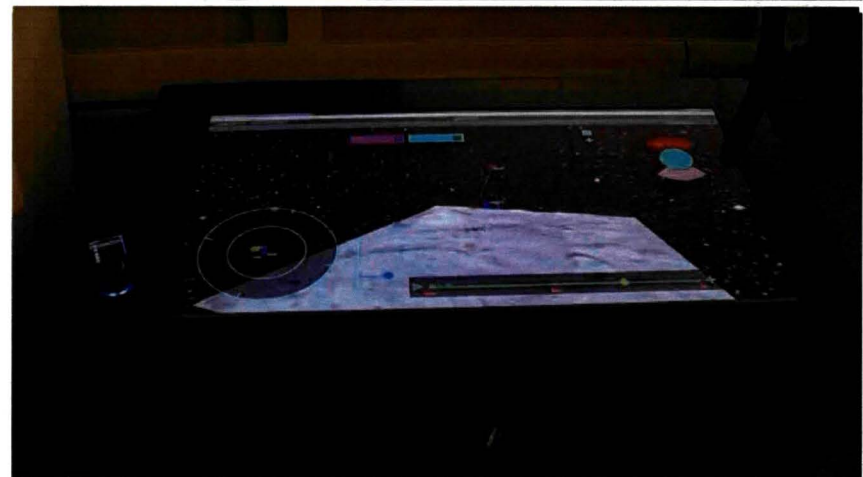
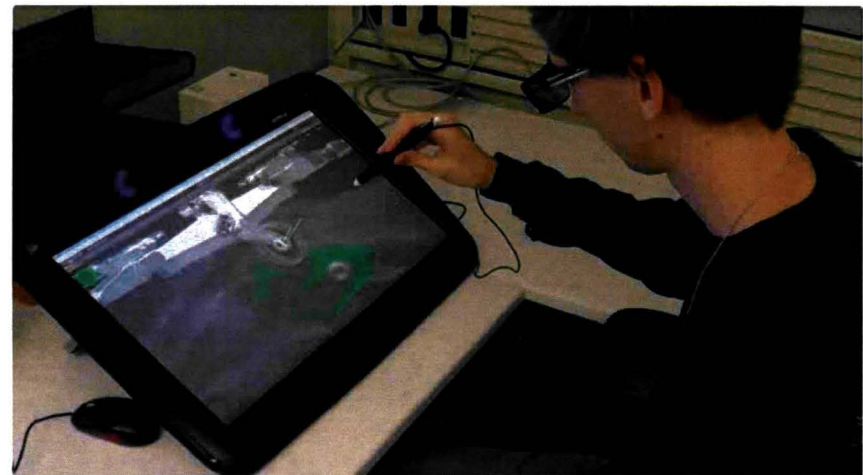
- Developed several natural user interfaces based on new-to-market or pre-release technologies
- Received highly positive feedback from test subjects who are experts in teleoperation and rover operations

- **Significance**

- InfiniteZ zSpace interface considered a candidate for mission operations
- Interface devices all support RAPID for multi-Center, multi-Agency applicability

- **Additional Information**

- Abstract accepted at IEEE Aerospace 2013: "Cockpit 2.0: Natural User Interfaces for Human Robotic Partnerships"



Click images for video



Human Systems Interaction: FY13 Tasks & Plans

September 19, 2012

David Mittman

Supervisor, Planning and Execution Software Systems Group

(818) 393-8232 FAX (818) 393-5074

David.S.Mittman@jpl.nasa.gov

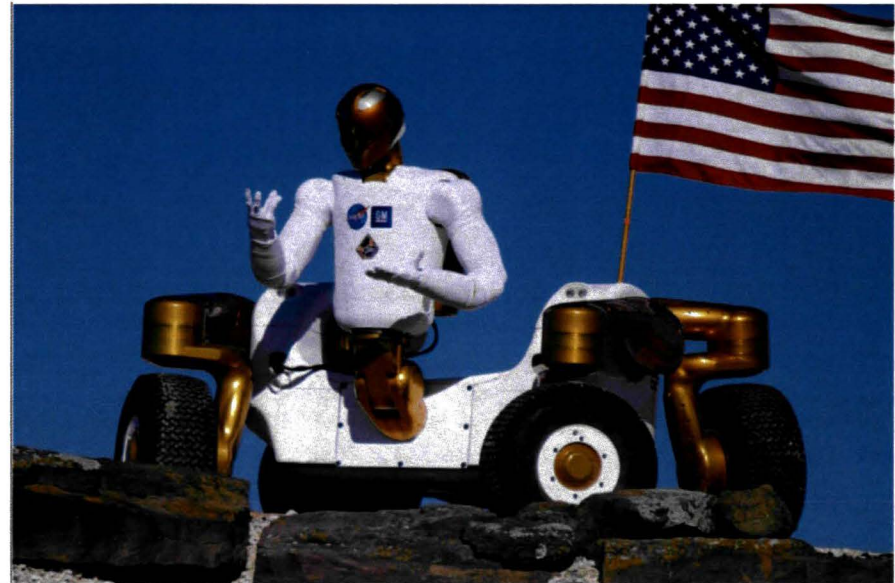


Providing a Unified Cross-Center Operations Platform

Task Lead: David Mittman (JPL)
Task Support: Rob Burrige (JSC)
Hans Utz (ARC)

Status of Work: The RAPID system for collaborative telerobotics includes SEV, Centaur 2, Robonaut 2, ATHLETE, K10, LSMS, EVAIS and EXARM; has been field tested over several years; works over NEO-class time delays with disruption; and supports transfer of large data sets through an asynchronous file transfer service. The RAPID collaboration has expanded to new NASA and international Agency relationships and is contributing to the development of international standards in telerobotics operations to enable NASA missions.

Task Description: Develop and test improvements to the RAPID system of common telerobotic monitoring and control messages and services. Develop operations technologies and processes for safe coordinated operations of humans and robotic systems. In FY13, the RAPID monitoring and control protocol will be extended to ease the integration and operation of robotic components from multiple organizations. In FY14, we will extend RAPID to incorporate the H.264 video format and continue NASA and community support for RAPID integration across organizations.



TABS Elements:

- Mobile Manipulation (TA 4.3.4)
- Distributed Collaboration (TA 4.4.5)
- Common Human-Systems Interfaces (TA 4.4.6)
- Multi-Agent Coordination (TA 4.5.4)

Milestones:

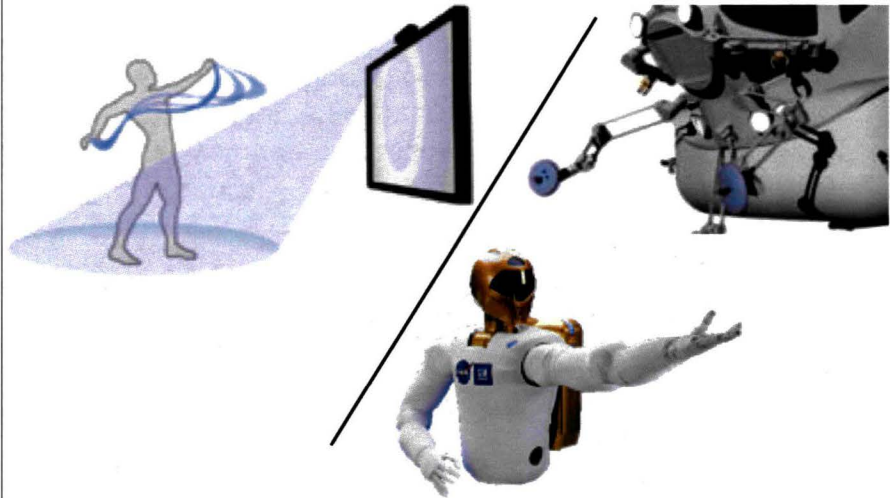
- Feb 2013: Design of the RAPID Service Integration Framework (SIF) complete.
- Sep 2013: Test RAPID SIF during test season integration phase.
- FY14: Develop, test and support RAPID extensions for mission-focused operations scenarios



Natural User Interfaces for Advanced Telerobotic Operations

Task Lead: Jeff Norris (JPL)

Status of Work: Effectively controlling a high degree-of-freedom robot is a challenging and often safety-critical task. As these systems approach human-like dexterity, the body of the operator becomes the most natural and effective control device. In addition, accurate tracking of the operator's pose enables the rendering of a more immersive virtual representation of the robot's environment. We have demonstrated and tested several natural user interfaces for manipulation task control for R2 (JSC) and ATHLETE (JPL).



Task Description: This task will use body-tracking input devices (i.e. Microsoft Xbox Kinect and accelerometer gloves) to immerse an operator in an accurate virtual model of the robot's environment, capture the intent of the operator, and safely execute mobility and manipulation tasks suitable for platforms such as Robonaut 2 and SEV. We will add motion planning capabilities to the natural user interface system, providing additional safety through the use of redundant degrees of freedom to avoid collisions, and infer motion strategies from operator input.

TABS Elements:

- Human-Systems Integration (TA 4.4)
- Multi-Modal Human-Systems Interaction (TA 4.4.1)
- Supervisory Control (TA 4.4.2)
- Intent Recognition and Reaction (TA 4.4.4)
- Remote Mission Operations (TA 7.5.3)

Milestones:

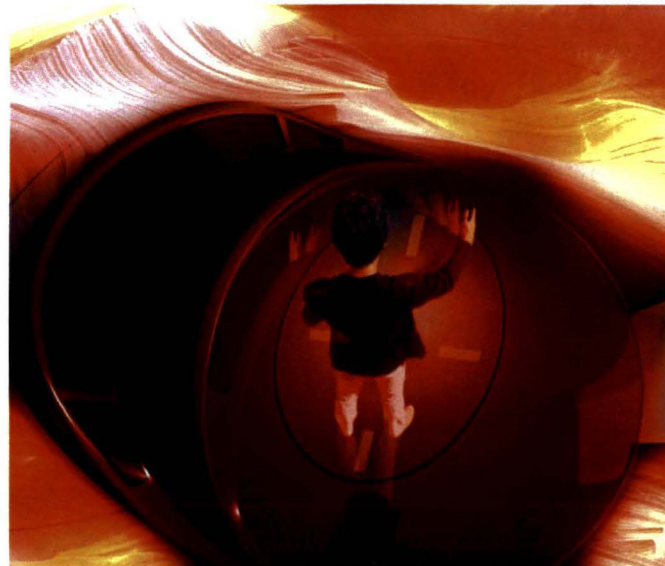
- Mar 2013: Recognition of operator path and pose for motion planning
- Sep 2013: Demonstration of motion planning in a cluttered environment
- FY14: Concurrent operation of mobility and manipulation capabilities



Sensor Systems for the Construction of Immersive Virtual Environments

Task Lead: Jeff Norris (JPL)

Overview: Immersive, “Holodeck”-like displays are powerful tools for exploration, but it is difficult to create detailed and accurate 3D virtual reconstructions of the environment to be explored that are suitable for use in these displays. Commercial sensor systems available today do not effectively address this challenge, leading to a proliferation of labor-intensive and low-quality solutions that dramatically limit the utility of immersive displays.



Task Description: This task will develop tightly integrated sensor and software systems that rapidly capture images and depth data of the surrounding environment and reconstruct a 360-degree 3D virtual model optimized for remote interactive display within common visualization software packages, game engines, and immersive display systems. The integrated system will provide reconstruction of a broad range of environments and offer easy integration with existing HRS assets via a RAPID-compliant interface.

TABS Elements:

Human-Systems Integration (TA 4.4)
Multi-Modal Human-Systems Interaction (TA 4.4.1)
Remote Mission Operations (TA 7.5.3)

Milestones:

Mar 2013: Complete design of a prototype sensor system
Sep 2013: Demonstrate prototype sensor system in the laboratory
FY14: Production of integrated, deployable sensor system



HRS FY12 Continuation Review

JSC: Organized By Theme

Bill Bluethmann, Ph.D.

September 19, 2012

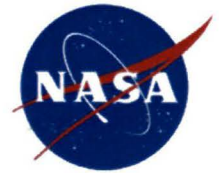
Theme: EVA Mobility



- Prototype Next Generation Jetpack for Flat Floor Testing
- Prototype hands free control of EVA Jetpack
- Complete Active Response Gravity Offload System for Suited Crew

Task 2.1.1: FY12 plan

Prototype Next Generation Jetpack for Flat Floor Testing



Task Lead:

Current status of work:

A class III Engineering Unit from the USA Simplified Aid For EVA Rescue (SAFER) project has been integrated with an air bearing sled for use in initial performance assessments and preliminary operational procedure development



FY12 Task Description:

- Develop functional requirements using
 - Simulations to define system properties
 - Prototype evaluations (SAFER on air bearing floor) to define operational constraints
- Develop and demonstrate first generation prototype
- Begin development of flight concept design

Note: Aug date moved to Sept in project plan

OCT Roadmap Linkage :

TA4.2.4 Small Body / Microgravity Mobility

TA7.3.1 EVA mobility

Milestones:

Dec 11: Concept development for first generation prototype

May 12: First generation prototype design drawings complete

Aug 12: first generation prototype available for testing on air bearing floor

FY13/14: Engineering evaluation and testing/ARGOS integ

Task 2.1.1: FY12 Accomplishments: Prototype Next Generation Jetpack for Flat Floor Testing



- Approach

1. Develop prototype for testing on the air bearing floor in JSC's building 9.
2. Develop flight design of EVA jetpack compatible with appropriate Advanced Exploration Systems (AES) projects
3. Solicit feedback from astronauts with EVA SAFER training and experience

- Accomplishments

- Conceptualized, designed, and built a prototype EVA jetpack for use on JSC's air bearing floor
 - Jet pack is at metal finish the week of the review
 - Initial testing is planned before the end of Sept 2012
 - Enable control through hand-free operation (HRS task 4.3.1)
- Developed fault-tolerant propulsion system concept for flight design
- Flight design of jetpack is compatible with the Multi-Mission Space Exploration Vehicle (MMSEV)/Suit port/Advanced Suit projects within the Advanced Exploration Systems (AES) program.
- Evaluated flight designs using fit checks with low fidelity mockups on suit ports and advanced suits.
- Evaluated jet locations by testing design in the Virtual Reality Laboratory

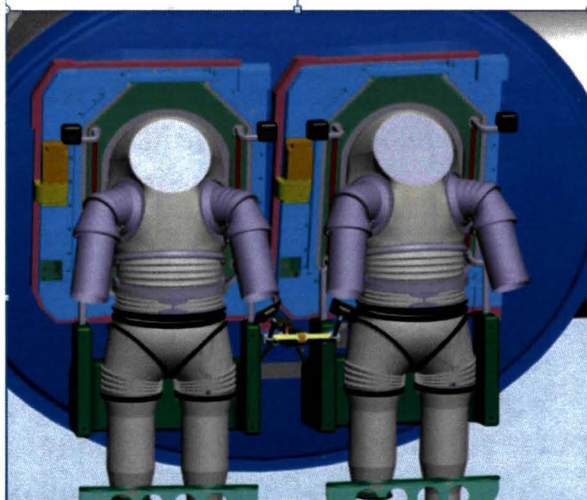


Task 2.1.1: FY12 Accomplishments: Prototype Next Generation Jetpack for Flat Floor Testing

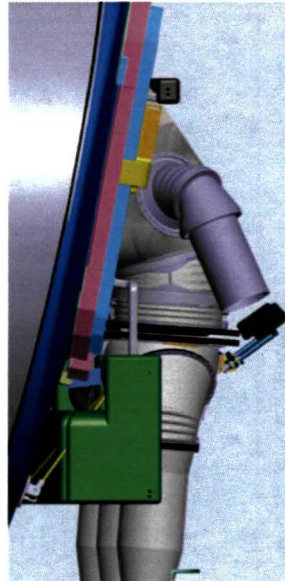


Design Trade with MMSEV and Suit ports

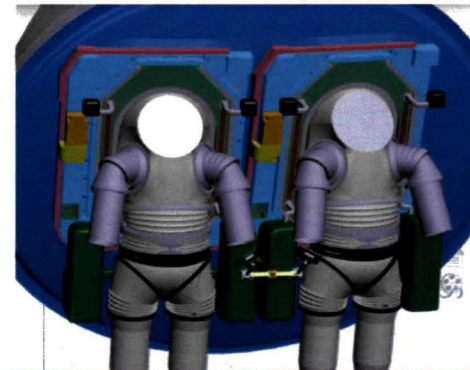
Backbox on Suitport



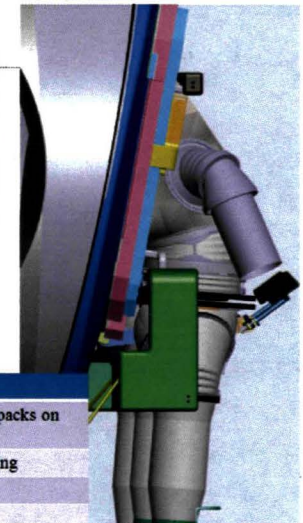
Pros	Cons
Simplifies plumbing	Restricts movement backwards
Larger clearance between Jetpacks on Suitports	Slightly higher tank weight
	Sits lower on suit



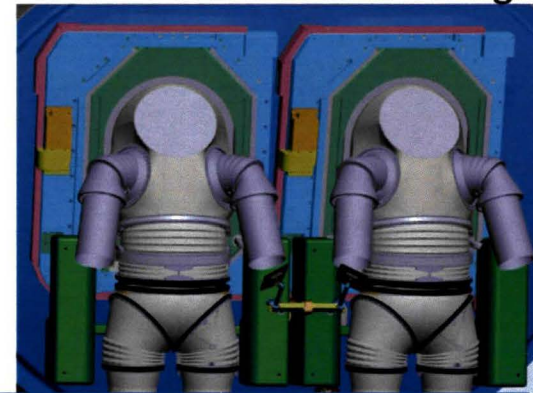
Twinpack on Suitport



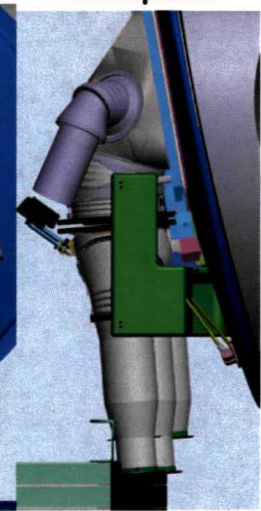
Pros	Cons
Minimal backwards movement restriction	Small clearance between jetpacks on suitport
Sits higher on suit/SIP assembly	More complex plumbing



All Lower Thruster Design on Suitport



Pros	Cons
Simplifies plumbing – no top antennas	Loss of prop efficiency
No top attachment to SIP	Small clearance between jetpacks on suitport
No routing tubing on SIP	



Task 2.1.1: FY13 Plan

Prototype Next Generation Jetpack for Flat Floor Testing



Task Lead: Kevin Lewis(JSC)

Current status of work:

- Developed MMSEV/Suit port/Advanced Suit compatible concept design following trade studies based on fit checks and flying capability assessments in the Virtual Reality Laboratory
- Fabricated prototype system for demonstration on the Flat Floor
- Developed fault-tolerant propulsion system concept for flight design



Task Description:

- Evaluate prototype jetpack performance on flat floor
- Reassess jetpack packaging to align with new Agency goals.
- Develop flight concept design
- Develop and demonstrate second generation prototype
 - On flat floor
 - In Virtual Reality Laboratory
 - In Active Response Gravity Offload System (ARGOS)

OCT Roadmap Linkage

TA 4.2.4 Small Body / Microgravity Mobility
TA7.3.1 EVA mobility

Milestones:

Nov 2012: Evaluate First Generation Prototype on flat floor
Dec 2012: Concept Development for second generation prototype
May 2013: Second Generation Prototype design drawings complete
Sept 2013: Second Generation Prototype available for testing on flat floor and in ARGOS

Task 4.3.1: FY12 plan

Prototype hands free control of EVA Jetpack

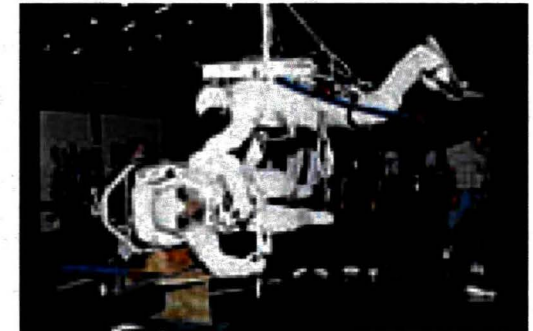


Task Lead: Jennifer Rochlis-Zumbado (JSC)

Task Support: JPL

Overview:

The Simplified Aid for EVA Rescue (SAFER) is currently an astronaut third line of defense for safety during EVA. When used, it requires the use of both hands of the crewman. As the system evolves into a mobility solution, the crew will use their hands for performing work, necessitating approaches for commanding the jet pack without using their hands.



FY12 Task Description:

- Conceptualize and implement a hands free method of control for an EVA jetpack.
- The task will assume the astronaut is in a pressure suit.
- Various technologies such as voice, heads up displays, eye tracking, etc. will be investigated.
- Based on a combination / singular technology, a control method will be applied and tested using the SAFER DTO on an air bearing floor to simulate low friction in 3 of 6 degrees of freedom.

OCT Roadmap linkage:

TA 4.4.3 Robot to suit interfaces

TA4.4.6 Common human systems interfaces

TA 7.3.2 EVA mobility

Milestones:

Jan 12 Complete evaluation of various hands free technologies

Sep 12 Initial test with SAFER on air bearing floor

FY13/14 integrated testing with SAFER, begin development of suit interfaces

Task 4.3.1: FY12 accomplishments

Prototype hands free control of EVA Jetpack

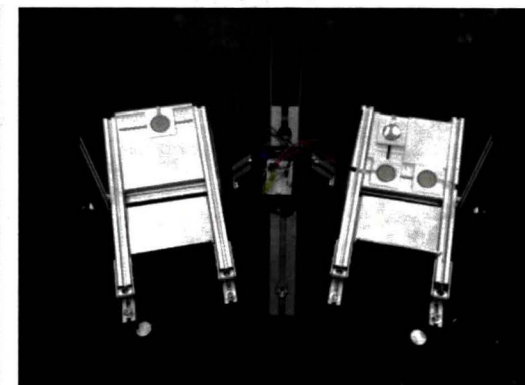
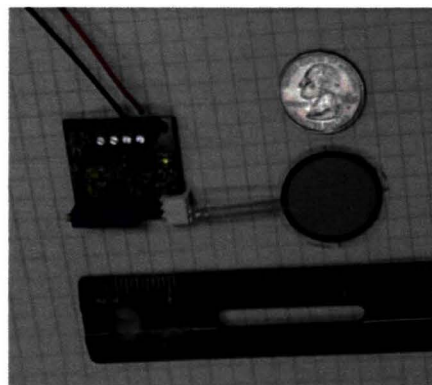
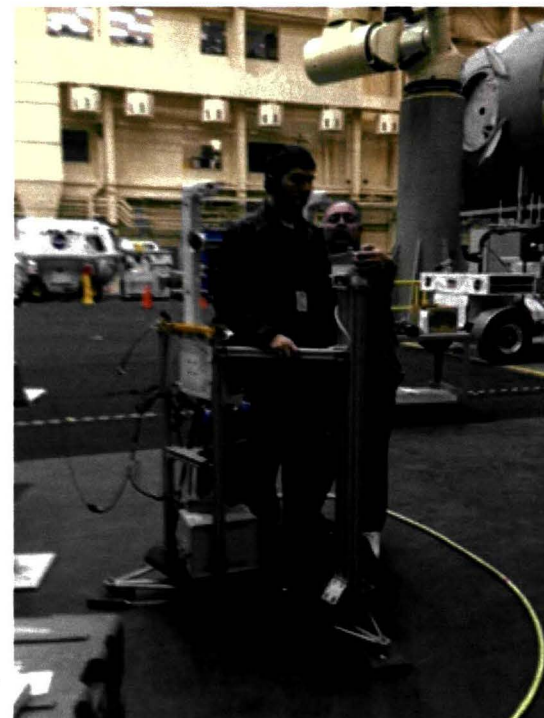


Approach

- Develop approach to providing hands-free control for future EVA jetpacks or other current robotic systems

Accomplishments

- Investigated multiple options for hand-free control before down selecting to voice commanding and foot sensor control
 - Conducted interviews with astronauts regarding their SAFER experiences, training and piloting methods
- Developed a modern PC interface to 1990's SAFER Avionics
- Purchased wearable computer headset hardware with embedded microphone, head tracker and adjustable display screen
- Tested voice control of thrusters in the Virtual Reality Laboratory and on de-rated SAFER unit
- Developed headset GUI to send commands to jetpack on Wifi
- Developed and integrated foot sensor assembly hardware with the jetpack test unit



Task 4.3.1: FY13 plans

Prototype hands free control of EVA Jetpack



Task Lead: Jennifer Rochlis Zumbado (JSC)

Task Support: JPL

Current status of work:

- Investigated multiple technologies
- Down selected to two concepts - voice and foot control
- Integrated control systems with USA SAFER Engineering Unit and Virtual Reality Laboratory
- Re-hosted control systems to First Generation Jetpack



Task Description:

- Evaluate hands free control systems in Virtual Reality Laboratory and on flat floor with First Generation Jetpack
- Refine hands free control system and integrate operator display
- Integrate second generation prototype hands free control system with Second Generation Jetpack
- Demonstrate second generation prototype hands free control system
 - On flat floor
 - In Virtual Reality Laboratory
 - In Active Response Gravity Offload System (ARGOS)

OCT Roadmap linkage:

TA 4.2.4 – Small Body / Microgravity Mobility
TA 4.4.3 – Robot-to-Suit Interfaces

Milestones:

Nov 2012 – Evaluate hands free control system with First Generation Prototype on flat floor

Jan 2013 – Complete evaluation of display and control technologies

Sept 2013 – Test with Second Generation Jetpack on flat floor and in ARGOS

Task 2.3.2: FY12 plan

Complete Active Response Gravity Offload System for Suited Crew



Task Lead: Larry Dungan (JSC)

Current status of work:

- ARGOS is currently a human-rated facility with a payload capacity of 250 lbs.
- ARGOS interfaces to a payload via a gimbal that aligns rotational axes with center of mass.
- Upgrades initiated in FY10 will improve system performance and increase capacity to accommodate suited crewmembers.



FY12 Task Description:

- Complete upgraded horizontal motion control system
- Complete upgraded vertical motion control system
- Integrate upgraded horizontal and vertical systems into existing ARGOS structure
- Design and fabricate a gimbal to interface a designated space suit to ARGOS

OCT Roadmap Linkage :

TA4.2.4 Small body/microgravity mobility
TA7.3.1 EVA mobility

Milestones

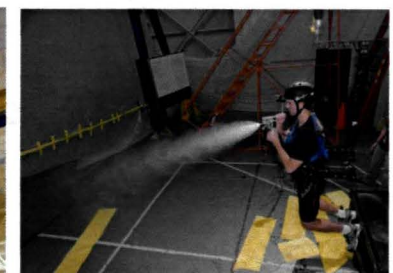
Feb 12: Complete integration of upgraded horizontal and vertical systems on structure
May 12: Complete design of a gimbal to interface space suit to ARGOS
July 12: Complete fabrication of gimbal to interface space suit to ARGOS
Aug 12: ARGOS ready to support testing with suited crewmembers
FY13: Integration with SAFER and hand's free operation

Task 2.3.2: FY12 accomplishments

Complete Active Response Gravity Offload System for Suited Crew



- Completed upgrade of horizontal and vertical axis.
 - Upgrades responsiveness
 - Increases payload to from 250lb to 750lb (human rated) in Feb 2012
- Tested with Robonaut 2 legs starting in Feb 2012
- Tested with Advanced Crew Escape Suits (ACES) in June 2012
- Raised ARGOS structure 7 feet to accommodate pressure suits in July 2012
- Completed horizontal gimbal in August 2012
- Provided ARGOS support for a wide variety of customers
 - Pressurized ACES suits, AES Analogs program, ISS, Robonaut 2, Crew Training, and Fire Extinguisher Testing



Click image for video

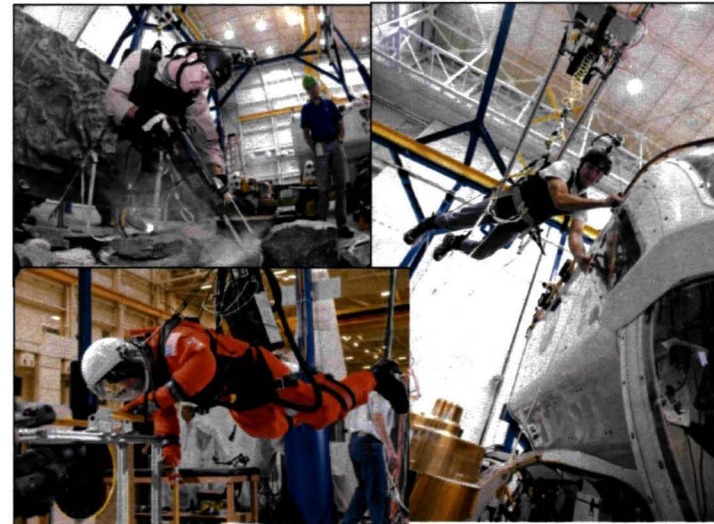
Task 2.3.2: FY13 plan Complete Active Response Gravity Offload System for Suited Crew



Task Lead: Larry Dungan (JSC)

Current status of work:

- Horizontal and vertical motion based systems were upgraded
- ARGOS is a human-rated facility with a payload capacity of 750 lbs
- Pressurized ACES suit testing completed
- Structure height increased
- Mark III Suit gimbal design complete



Task Description:

- Fabricate a gimbal to interface Mark III space suit to ARGOS
- Integrate suit interfaces (air, cooling, etc) with ARGOS
- Complete pressurized suited testing for designated suits (ACES, Mark III, EMU, etc)

OCT Roadmap Linkage :

TA4.2.4 Small body/microgravity mobility
TA7.3.1 EVA mobility

Milestones

Dec 2012: Fabrication of pressurized suit gimbal complete
Jan 2013: Suit interfaces installed
Sept 2013: Pressurized suit testing completed

Theme:

Precursor Missions (support AES Analogs)



- Prototype ballistic sensor/payloads
- Conceptual design of flyer/rover team
- Test Existing Rover in Lunar Precursor Scenario
- Test Existing Robot in Lunar Precursor Level of Tasks & Comm

Task 2.1.2: FY13 plan

Prototype ballistic sensor/payloads

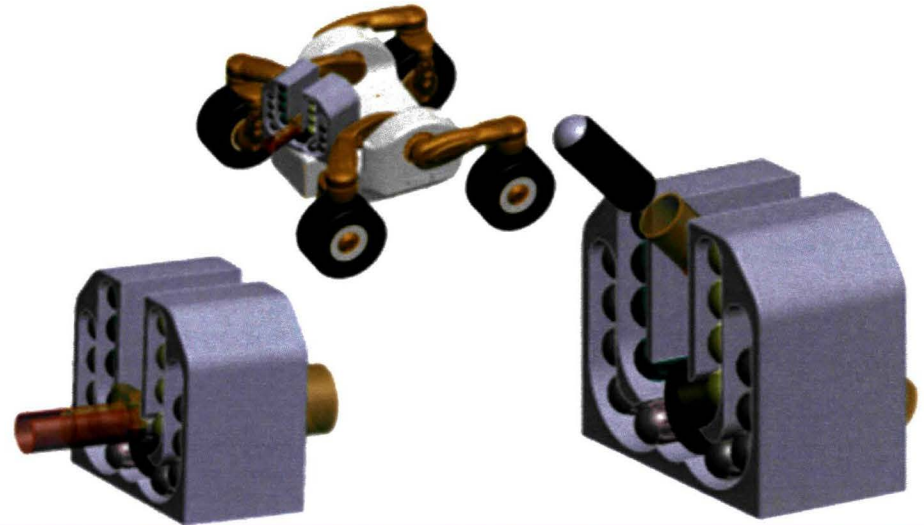


Task Lead: Lyndon Bridgwater (JSC)

Task Support: JPL, ARC, GRC, KSC

Current status of work:

New task in FY12



FY12 Task Description:

- Conceptualize, Design, Manufacture & Test an Electric Projectile Launcher System for deploying remote sensors at a distance from a roving platform.
- The system will have a selectable magazine to chose from a variety of sensor payloads which are build within a common shell.

OCT Roadmap Linkage:

TA4.1.3 Terrain mapping, classification and characterization

TA4.2.1 Extreme terrain mobility

TA7.3.2 – Surface mobility

TA7.3.3 Off-surface mobility

Milestones:

Nov 11: Design review for shell specifications & launch loads

Feb 12: Design review for base interface & volume constraints for attachment to rover system.

Jun 12: Initial assembly complete of prototype launcher & shell

Sept 12: Initial testing of prototype launcher and shell complete

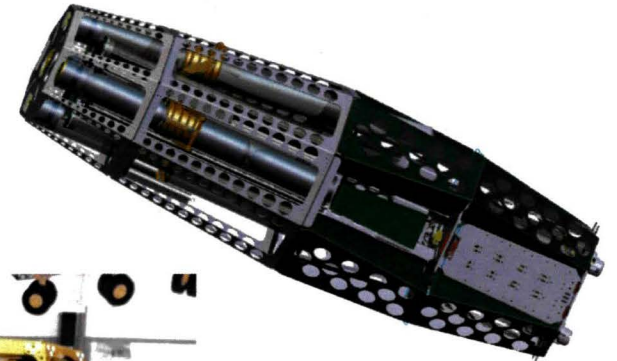
FY13: Integration with Centaur 2 base, testing

Task 2.1.2: FY12 accomplishments

Prototype ballistic sensor/ payloads



- Approach
 - Develop shell specification early in year
 - Highly integrated in computer aided design
 - Use low cost or rapid production approaches to fabrication when possible
- Accomplishments
 - Conceptualized, designed, fabricated prototype ballistic payload launcher
 - Shell specifications released in Nov 2011
 - Design assembly completed July 15
 - Developed test payloads using low cost molding approach for shells
 - Currently in final assembly. Initial checkout planned by Sept 28



Task 2.1.2: FY13 plan

Prototype ballistic sensor/ payloads

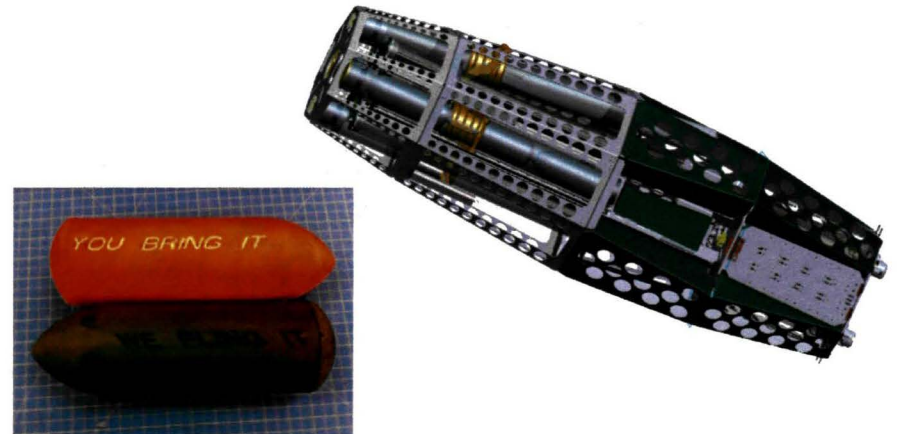


Task Lead: TBD

Task Support: JPL,ARC,GRC,KSC

Current status of work:

During FY12, the ballistic launcher was conceptualized, designed, fabricated and assembled. The system can hold up to four types of payloads and three of each type. The system uses a set of extension springs and electric motors to provide launch force.



Task Description:

During FY13, the primary focus will be performing engineering evaluation and testing on the ballistic payload launch system. The project has targeted demonstrating the system at a student competition (Lunabotics, Robo-RASCAL, FIRST, etc) to generate student interest in building payloads.

OCT Roadmap Linkage:

TA4.1.3 Estimation of terrain mechanical properties

TA4.2.3 Above Surface Mobility

Milestones:

Nov 2012: Complete checkout of ballistic launcher system

Jan 2013: Select student competition to demonstrate ballistic launcher system

July 2013: Complete demonstration of ballistic launcher system at student competition

Task 2.1.3: FY12 plan

Conceptual design of flyer/rover team



Task Lead: Mike Goza (JSC)

Task Support: JPL & Army

Context:

This new task will utilize the Centaur 2 base and leverage expertise in remotely controlled rotor craft.



FY12 Task Description:

- Design, Develop, and Test a launch-and-recovery system for a vertical take off / landing aircraft using the existing Centaur 2 (C2) as the rover base.
- Since the air vehicle will be exploring lava tubes, it will be relatively small in size and have the capability to hover.
- The system will be rugged enough to travel over rough terrain without damaging aircraft.
- Initially the aircraft will be remote controlled with potential for autonomous operation in the future.

OCT Roadmap Linkage:

TA4.2.1 – Extreme Terrain Mobility

TA4.2.2 – Above surface mobility

TA4.5.3 – Autonomous guidance and control

TA4.6.3 – Docking and Capture mechanism/interfaces

TA7.3.2 – Surface mobility

TA7.3.3 – Off-surface mobility

Note: Aug date moved to
Sept in project plan

Milestones:

Feb 12: Complete trade study for launch/recovery mechanisms in static test

Aug 12: Install system on Centaur 2

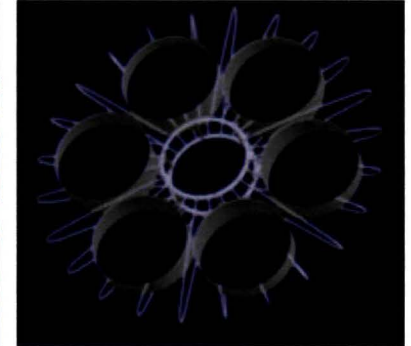
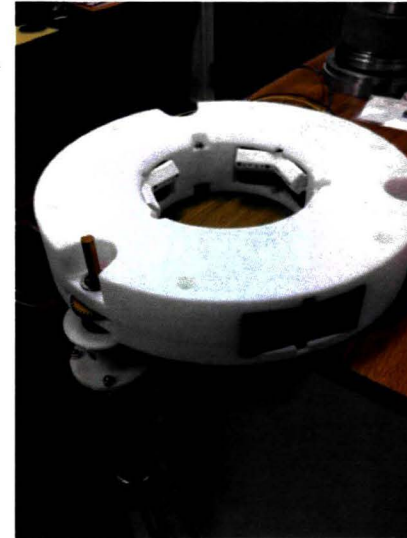
FY 13: Test launch/recover mechanism, perform hybrid exploration testing

Task 2.1.3: FY12 accomplishments

Conceptual design of flyer/rover team



- Approach
 - Use existing sensors, approaches, software tool to
- Accomplishments
 - Conceptualized, design and fabricated interface between flyer and Centaur 2 base
 - Developed flight controller for COTS hexacopter
 - Designed shell for flyer to improve safety
 - Updated Centaur 2 trajectory generators to run on flyer
 - Connect to flyer through HRS RAPID interface
 - Developed a battery charging interface between Centaur 2 and flyer platform
 - Adapted Autotrack Computer Vision System (ACVS) flown as DTO on STS-95 for landing on Centaur 2
 - Centaur 2 interface installed and automatic take off/landing planned by Sept 28.



[Click image for video](#)

Task 2.1.3: FY13 plan

Conceptual design of flyer/rover team



Task Lead: Mike Goza (JSC)

Current status of work:

During FY12, a heterogeneous mobility team of a rolling device and a flying device were prototype and initial capabilities were tested. An interface between the Centaur 2 rover and the flyer was built and the basic control



Task Description:

This task will build on the previous years HRS work to design, develop, and test a launch and recovery system for a vertical take off / landing aircraft using the existing Centaur 2 (C2) as the vehicle base. The task will expand upon the basic take off and landing autonomous functions developed in FY 12 and bring in existing HRS tools for controlling robots remotely.

OCT Roadmap linkage:

- TA 4.2.1 Extreme Terrain Mobility
- TA 4.2.3 Above Surface Mobility
- TA4.6.1 Relative Navigation Sensors
- TA4.6.3 Docking and Capture Mechanisms/Devices

Milestones:

- Nov 12 – Complete engineering evaluation of flyer/rover team
- Sept 13 – Combined exploration using Centaur 2 and Copter using HRS's PIGI tool

Task 2.4.2: FY12 plan

Test Existing Rover in Lunar Precursor Scenario

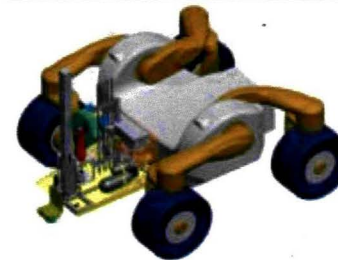


Task Lead: Darby Magruder(JSC)

Task Support: KSC

Current status of work:

FY11 field test demonstrated Robonaut 2/Centaur 2 remote operations over time delay.



FY12 Task Description:

This task evaluates vehicle design, performance, payload integration and negotiation and navigation of extreme environment terrain.

Three types of payloads utilized for this class of rover :

- Excavation (collecting soil to feed an ISRU plant)
- Sensing (for site survey or robotic reconnaissance)
- Manipulation (surface setup and repair)

OCT Roadmap Linkage :

TA 4.2.1: Extreme terrain mobility
TA 4.3.1: Mobile manipulation
TA 4.4.2: Supervisory control
TA7.3.1 Surface mobility

Milestones

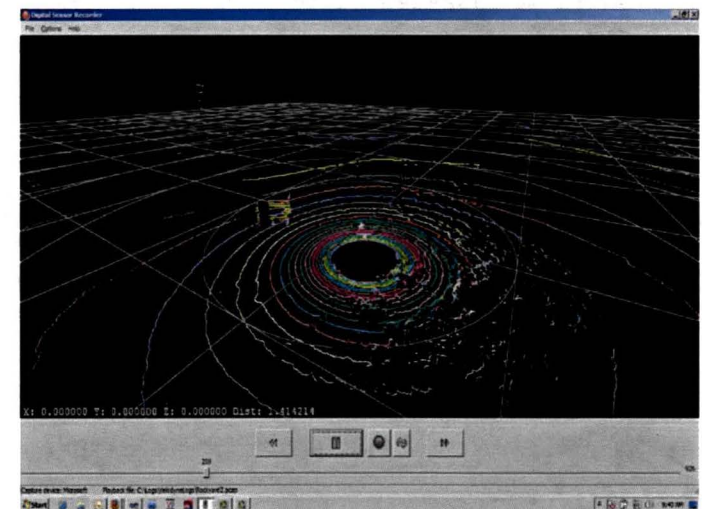
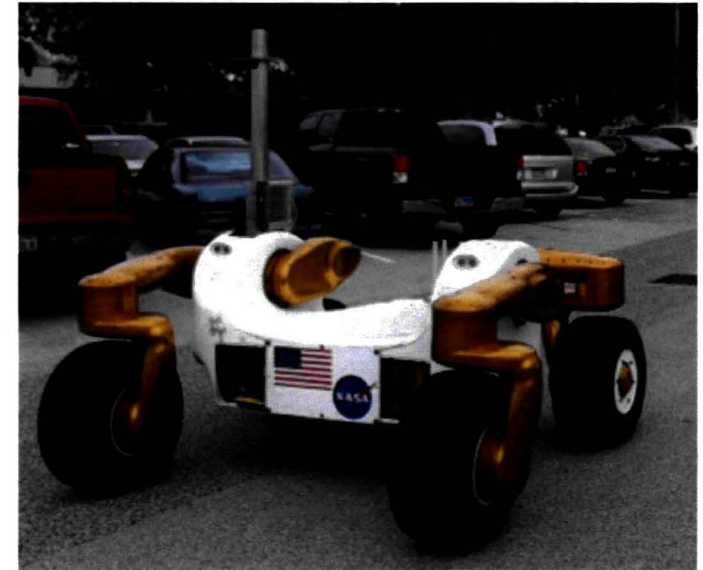
Jun 12: Centaur 2 hardware integration ready for field testing (at JSC)
Jun 12: Centaur 2 remote operations ready for field testing (at JSC)
FY13/14: Integration with new payloads

Task 2.4.2: FY12 accomplishments

Test Existing Rover in Lunar Precursor Scenario



- Approach
 - Support task 2.4.1 Advanced Navigation by adding sensing to Centaur 2 rover
 - Improve capabilities of Centaur 2 rover to be able to support field testing
- Accomplishments
 - Conceptualized, design, fabricated, integrated self contained sensor mast, containing
 - Velodyne Light Detection and Ranging sensor
 - Stereo pair
 - Inertial measurement unit (IMU)
 - Computing
 - Updated localization results to provide rover's location/velocity in both local and absolute frames
 - Completed development of systems by June 2012
 - Participated in field test activities at JSC July 12-17, presenting results to Robotic PI on July 16
 - Task not continuing in this form in FY13



Click image for video

Task 4.1.1: FY 12 plan

Test Existing Robot in Lunar Precursor Level of Tasks & Comm



Task Lead: Kimberly Hambuchen(JSC)

Task Support: Matthew Deans (ARC)

Current status of work:

- The Centaur 2 robot currently is designed for remote operations using the RAPID protocol.
- Testing is ongoing under time delays similar to those experienced at a near-Earth object.
- Autonomous navigation capabilities for small rovers have been tested and proven successful in multiple terrain sites on other small rovers.



Communication delay and outage



FY12 Task Description:

- Demonstrate remote operations of the Centaur2 robot with ISRU payload over lunar-like time delays.
- Communication infrastructure and operator interfaces will be as close as possible to applicable lunar precursor missions.
- Predictive techniques using models of robot behavior will be applied to accommodate for the time delays expected, and human interfaces will be upgraded to provide the highest situational awareness possible.
- Demonstrate remote supervision of an autonomous robot in the presence of dropped communication links, focusing on 5-10 minute outages, which will equate to about 1000 meters of continued robot operations.

OCT Roadmap linkage:

TA 4.1.1 3D perception
TA4.2.1 Extreme terrain mobility
TA4.4.1 Supervisory control
TA4.4.6 Common human-systems interfaces
TA7.1.1 Destination reconn, prospecting and mapping
TA7.3.2 Surface mobility

Milestones

Jun 12 Centaur 2 remote operations ready for field testing (at JSC)

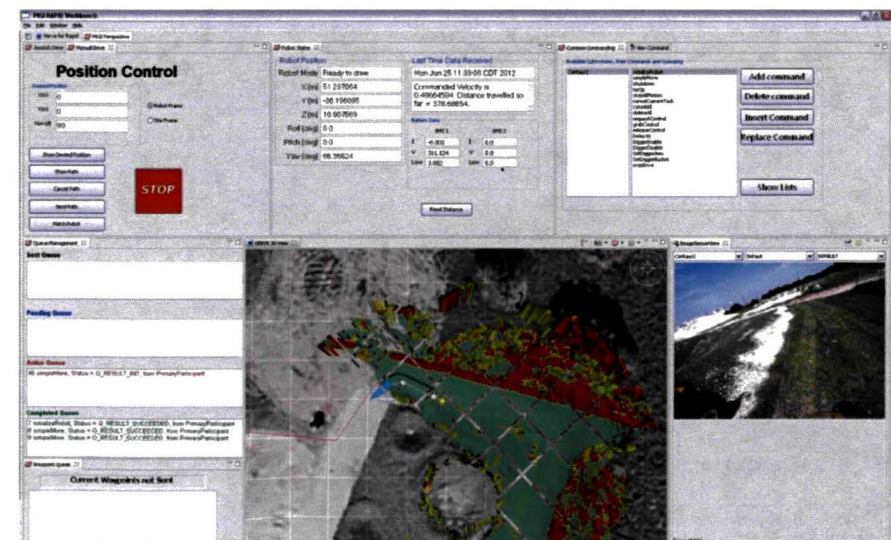
FY13/14 Integrate C2 with other and new payloads

Task 4.1.1: FY12 accomplishments

Test Existing Robot in Lunar Precursor Level of Tasks & Comm



- Approach
 - Support task 2.4.1 Advanced Navigation by adding new capabilities into time delayed control software
- Accomplishments
 - Added maps into predictive, interactive graphical interface (PIGI) tool
 - Developed new trajectory planning algorithms to support map generation and display
 - Completed development of systems by June 2012
 - Participated in field test activities at JSC July 12-17, presenting results to GCD Robotics PI on July 16
 - Began porting PIGI functionality to robotic operation system (ROS)
- This task will not continue in current form in FY13



Theme:

In space Work (Arms for Advance Exploration Systems)



- Prototype Dexterous Sampling Arm for Space Exploration Vehicle (SEV)

Task 3.2.2: FY12 plan

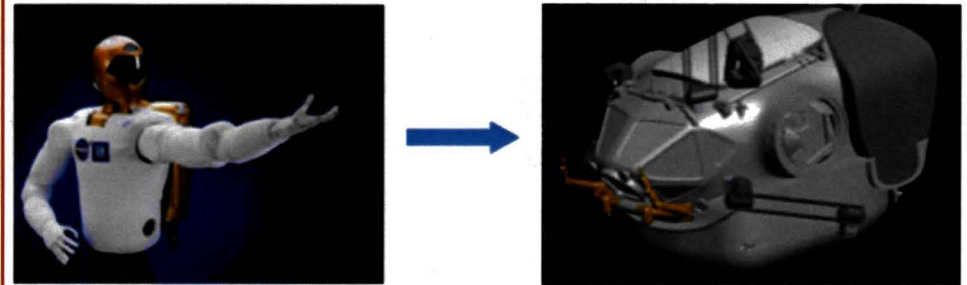
Prototype Dexterous Sampling Arm for Space Exploration Vehicle (SEV)



Task Lead: Ron Diftler (JSC)

Current status of work:

- In FY 2011 the Robonaut 2 (R2) system was launched to the International Space Station.
- This is the second generation of NASA's humanoid robot, integrating the latest advances in dexterous manipulator design, joint torque sensing, tactile sensing, and impedance control for interaction with the robot's environment.
- The same technology advances that allow Robonaut to manipulate objects and interact with its environment could be adapted to allow the SEV to do the same.



R2 derived dexterous arms for MMSEV

FY12 Task Description:

- Design and build prototype of dexterous robotic manipulators for the SEV that incorporate the sensing and control technologies of the R2 arm/leg joints.
- Build and test the necessary SEV mounting interface through a variety of con-ops.
- In FY13 and FY14, these arms will be integrated onto the MMSEV and tested in appropriate analogs.

OCT Roadmap areas:

- TA4.3.2 Dexterous manipulators
- TA4.3.6 Robotic drilling and sample processing
- TA4.4.2 Supervisory control
- TA4.4.7 Safety, trust and interfacing of Robotic/Human proximity operations

Milestones:

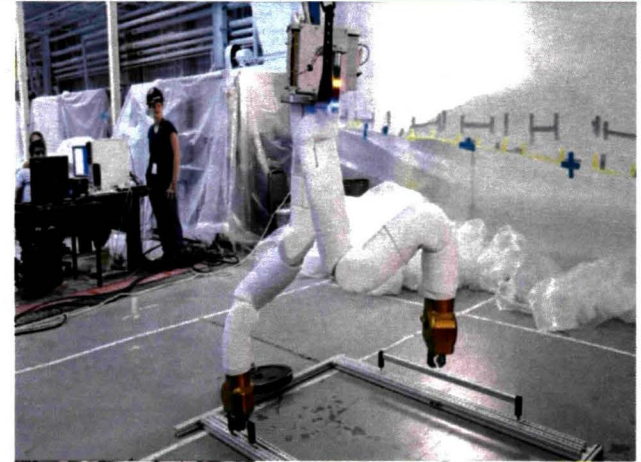
- May 13 Conceptual design review analyzing reach, mounting, and control techniques
- Sept 12 Initial assembly complete of a prototype dexterous arm for SEV
- FY13 integration onto MMSEV, engineering testing at analogs
- FY14 integrated analog mission testing on MMSEV

Task 3.2.2: FY12 accomplishments

Prototype Dexterous Sampling Arm for Space Exploration Vehicle (SEV)



- Approach
 - Leverage development of Robonaut 2 technologies; ISS climbing legs to adapt for MMSEV integration in FY13
- Accomplishments
 - Completed a reach study of placing dexterous arms on a 2nd generation MMSEV in March 2012
 - Completed assembly of arm in July 2012
 - Initial motion of dexterous arms in August 2012



[Click image for video](#)

Task 3.2.2: FY13 plan

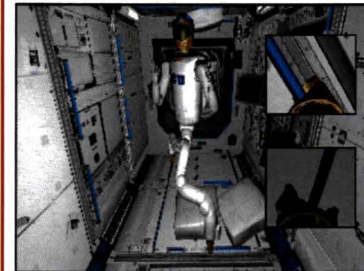
Prototype Dexterous Sampling Arm for Space Exploration Vehicle (SEV)



Task Lead: Ron Diftler (JSC)

Current status of work:

During FY12, the HRS project built a pair of dexterous arms for integration onto the Advanced Exploration Systems (AES) Multi-mission Space Exploration Vehicle (MMSEV). The arms derived from the Robonaut 2 ISS climbing legs.



R2 derived dexterous arms for MMSEV

Task Description:

- During FY13, the focus of this task will be to determine how they may be used during an L2/waypoint mission to serve as a robotic servicing tool. The target customer of this work still is the MMSEV project; although the focus of the MMSEV project is changing during FY13. Should the MMSEV call for integration, the arms will be integrated in FY13 and tested in FY14.

OCT Roadmap areas:

- TA4.3.1 Robot Arms
- TA4.3.2 Dexterous manipulators
- TA4.3.4 Mobile Manipulation
- TA4.4.7 Safety, trust and interfacing of Robotic/Human proximity operations

Milestones:

- May 13 Dexterous arm integration design review
- Sept 13 Deliver dexterous arms to MMSEV project

Task: 4.2.x

Advanced Robotic Operations Interfaces



Task Lead: Sharon Goza (JSC)

Overview: Effectively controlling a high degree-of-freedom robot is a challenging and often safety-critical task. With the increase in capability and popularity of tablet computers, portable gesture interfaces can be more easily implemented for intuitive robotics control.



Task Description:

This task will use a tablet device to demonstrate touch gesture control of common robotic operations. Initially, computer generated images will be used to simulate robotic vision and depth sensing. This may be expanded to incorporate live video and depth sensing data in a future task.

OCT Roadmap linkage:

TA 4.4.1 Multi-modal Human Systems Interaction
TA 4.4.2 Supervisory Control
TA 7.5.3 Remote Mission Operations

Milestones:

Nov 2012 – Gesture tablet interface prototype completed.
Dec 2012– Demonstration of graphics based tablet gesture interface system.

Task 2.2.x: Extreme Terrain Mobility Testbed



Task Lead: Bill Bluethmann (JSC)

Overview:

In the National Research Council's (NRC) review of NASA's Space Technology Roadmaps and Priorities, the ability to maneuver robotic devices into extreme terrain (robotic and crewed) was listed as a top technical challenge in the TA04 Robotics, Tele-Robotics and Autonomous Systems.



Task Description:

During FY13, HRS team members will develop a testbed for extreme mobility. This testbed will expand on lessons learned during the development of the Chariot chassis and the Centaur 2 base. During the development, certain system design and subsystem selections will be targeted for direct path toward flight (provided for budget constraints). The testbed will focus on technologies that will be beneficial on earth as well, including; by-wire operation, new batteries, fail operation avionics, and active suspension.

OCT Roadmap linkage:

TA4.2.1: Extreme Terrain Mobility
TA7.3.2 Surface Mobility

Milestones:

Sept 2013: Complete fabrication of parts for extreme mobility testbed
Dec 2013: Complete assembly of extreme mobility testbed
August 2014: Complete engineering evaluation of extreme mobility testbed

Task 4.x.x: Develop software to support adjustable autonomy



Task Lead: Jodi Graf(JSC)

Overview

Over the past number of years, the HRS project has focused on controlling robots over time delay. As new missions are proposed that may include direct teleoperation, the set of tools for controlling robotics will be expanded to be flexible depending on the situation; teleoperation, supervision or autonomy. New development will include adding capability both on the remote robot and at the human control interface



Task Description:

- Develop on-board robotic software and ground control software to support supervisory control, including direct tele-operation.
 - Software will be robust to noisy sensing
 - Software will be robust to limited/inconsistent/delayed communications with the ground control station.
- Test on Centaur2

OCT Roadmap linkage:

- TA4.4.2 Supervisory control
- TA4.5.5 Adjustable Autonomy
- TA4.5.7 Planning and Motion Planning with Uncertainty

Milestones:

- Dec 2012: Establish support for two-way supervisor /robot interaction.
- May 2013: Initial testing of adjustable autonomy software.
- Aug 2013: Software ready to test at JSC Rockyard.



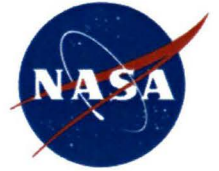
Human Robotic Systems

KSC 2012 review and
proposed subtasks for 2013

KSC PI: Rob Mueller
KSC PM: TBD

Task 3.2.3

Tool Change-out Interface Umbilical Integration

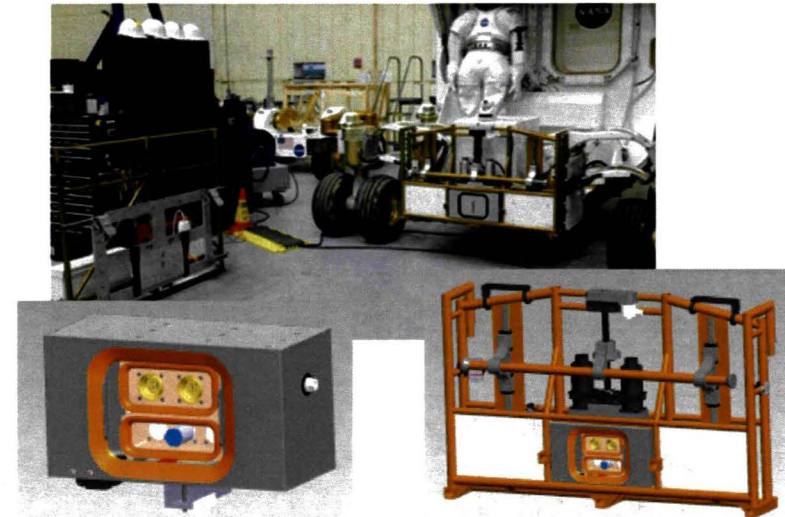


Task Lead: Rob Mueller (KSC)

Task Support: Ed Herrera (JSC)

Current status of work:

- During FY11 the modular Tool Change-out interface umbilical system was designed and fabricated with one electrical connector, one data connector and one cryogenic fluid connector.
- Now it needs to be integrated into the Tool Change-out Interface structure and SEV to function seamlessly.



FY12 Task Description:

- Address sets of requested changes to the Tool Changeout interface based on FY11 lessons learned.
- Integrate the umbilical system hardware and software into the Tool Changeout Interface to allow power, data and fluids transfer to the work package, such as a Portable Utility Pallet (PUP), or another payload.
- Pursue optimization of structural elements in conjunction with next generation mobility platform design.

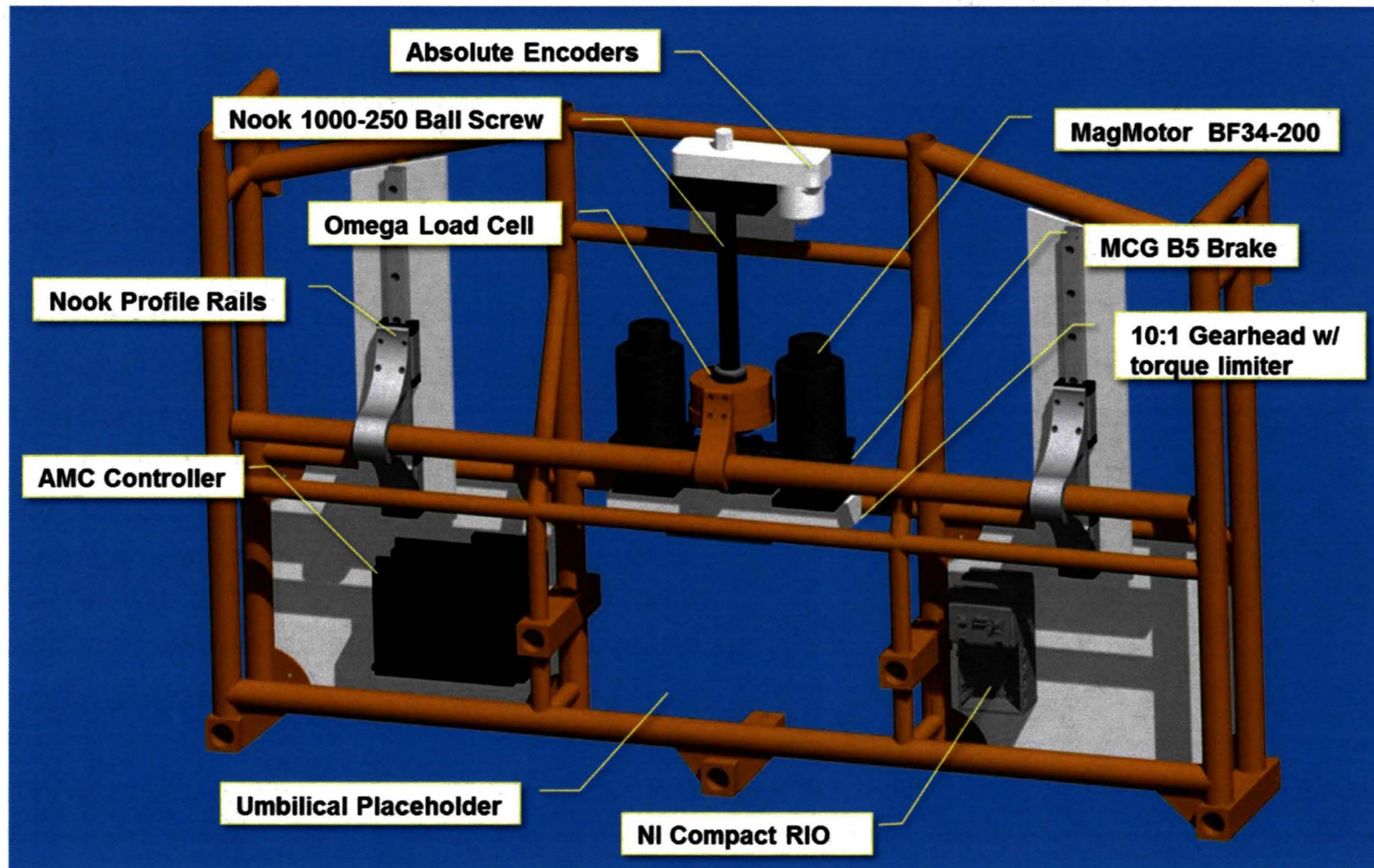
OCT Roadmap areas:

- TA 4.6.3 Autonomous Rendezvous and Docking Interfaces
- TA 4.7.1 Modularity/Commonality Serviceable Interfaces
- TA 4.5.5 Adjustable Autonomy
- TA 7.1.3 Consumables Production
- TA 7.1.4 Manufacturing and Infrastructure Emplacement

Milestones

- June 12: Software and Hardware Complete
- Aug 12: Validation Testing Complete (KSC)
- Sept 12: Integration at JSC

SEV Quick Attach Mechanism (FY11)



Key Milestone – June 2012

Task 3.2.3: Tool Change-out Interface Umbilical Integration



Objective: Transfer cryogenic fluids and power / data in an automated quick attach mechanism for SEV Payloads

Key Accomplishment:

- Developed a modular umbilical interface system with multiple connectors gang mounted on a six degree of freedom plate mechanism which enables highly misalignment tolerant blind mating operations
- Integrated software and operational sequences as well as automated checkouts
- Tested the fluid/electrical interface with the SEV to show an automated quick attach mating operation.

Milestones

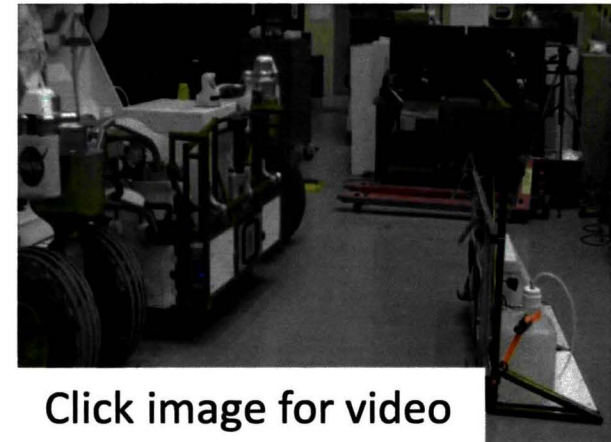
June 2012: Software and Hardware Complete

Aug 2012: Validation Testing Complete (at KSC)

Sept. 2012: Integration into SEV (at JSC)

Significance:

- Allows payloads to be automatically mated to the SEV without an Astronaut EVA
- Provides fluids/ electrical / data interfaces
- Allows Portable Utility Pallet (PUP) use with Fuel Cell & other payloads

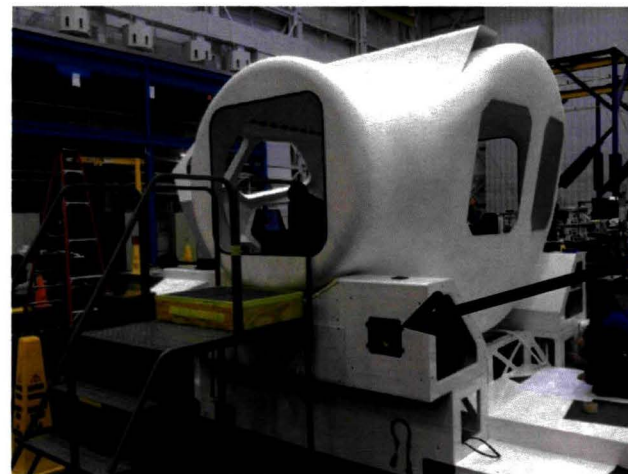
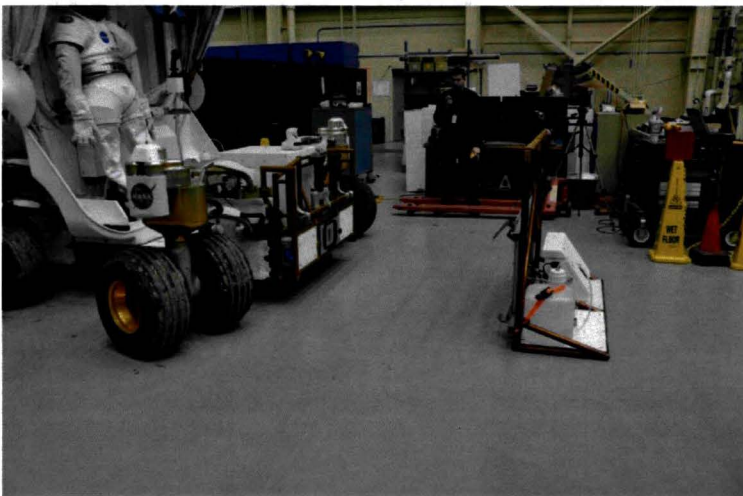
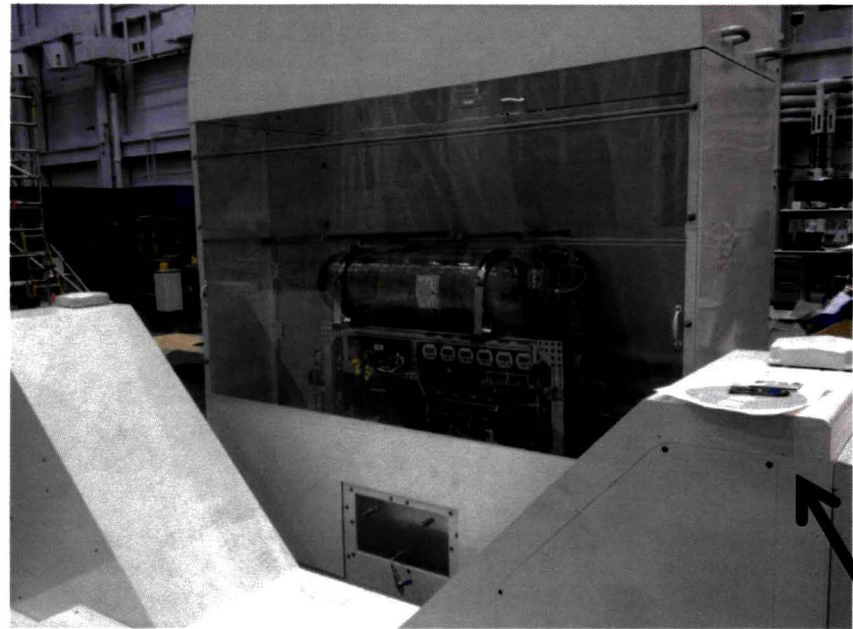


MMSEV Gen 1 Work Package Interface



SEV Automated Umbilical System

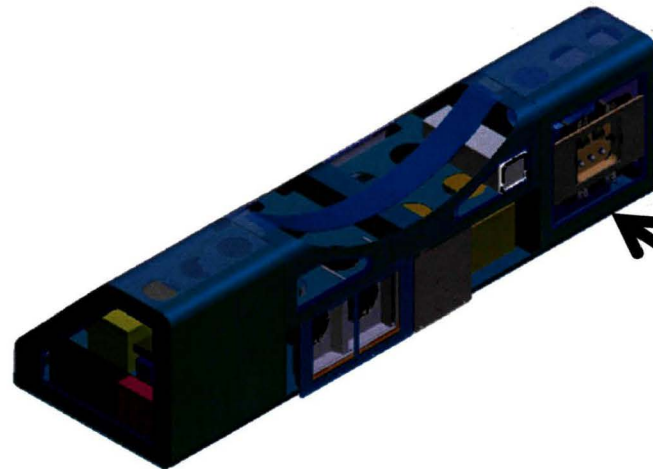
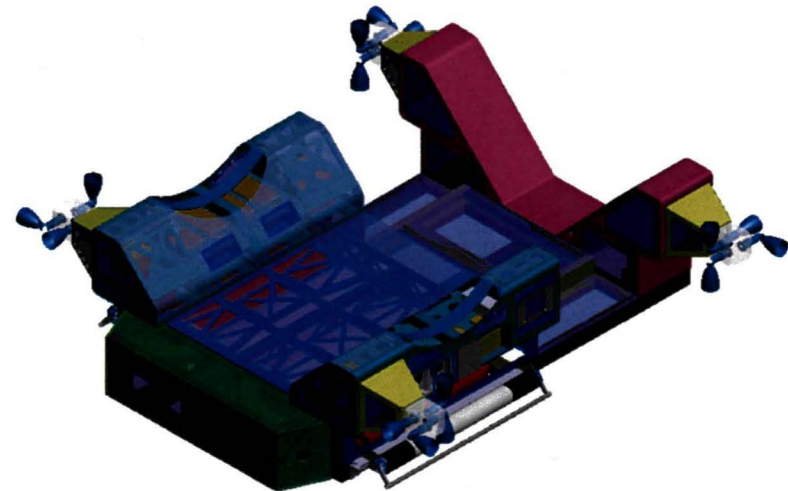
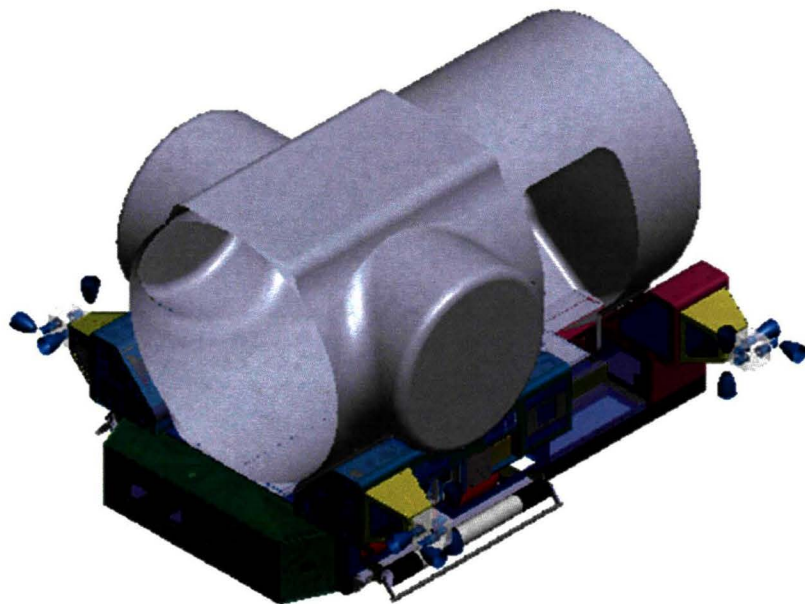
Umbilical Photos and Video



AES MMSEV
RCS Sled

KSC
Umbilical

MMSEV Sled Test



KSC Umbilical
Mock-Up



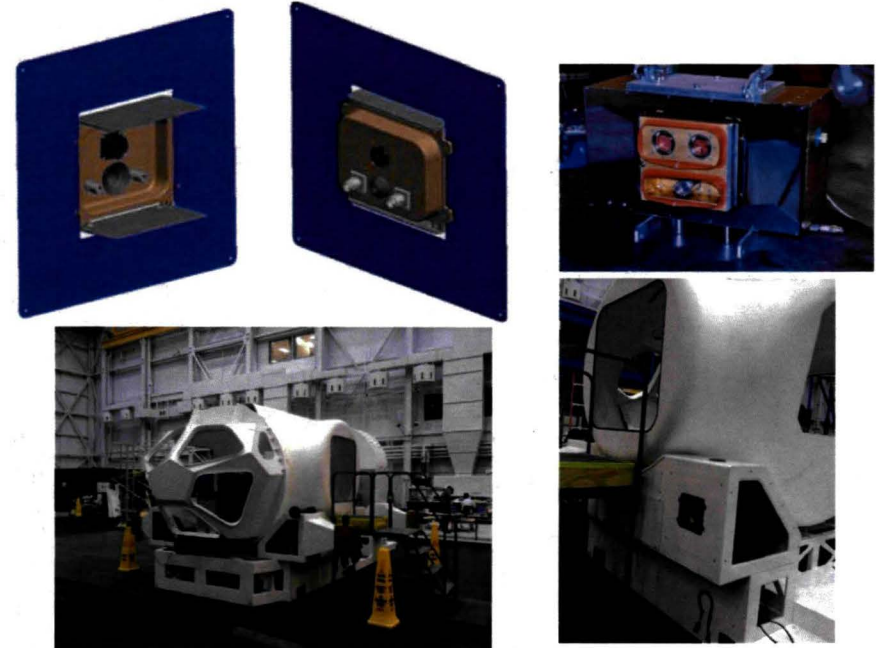
Task 3.2.3: Tool Change Out Interface Umbilical Integration

Task Lead: Rob Mueller (KSC)

Task Support: Ed Herrera (JSC)

Current status of work:

- The umbilical was upgraded and completed so that a fully automated, blind mate connection can occur with a payload such as the Portable Utility Pallet (PUP), Fuel Cell, Excavation Implement or future payloads.
- In FY12 the integration of software and operational sequences as well as automated checkouts were incorporated into the umbilical system with help from JSC SEV engineers. Testing occurred at JSC.



FY13 Task Description:

Second Generation SEV Chassis. A concept will be generated (with the JSC team) for replacing the external frame structure with an integrated internal structural solution in a second generation SEV chassis design, which will be highly mass efficient and elegant. The integration of the existing modular umbilical system will be studied and a concept will be proposed to the JSC team.

OCT Roadmap linkage:

TA 4.6.3 Docking & Capture Mechanisms/Interfaces
TA 4.7.1 Modularity/Commonality for Serviceable Interfaces
TA 4.5.5 Adjustable Autonomy
TA 7.1.3 Consumables Production
TA 7.1.4 Manufacturing and Infrastructure Emplacement

Milestones:

June 2013: 2nd Gen MMSEV Umbilical Concept identified
Sept. 2013: 2nd Gen MMSEV Umbilical Report Completed

Task 3.3.1: C2 Volatiles Mining End Effector Development

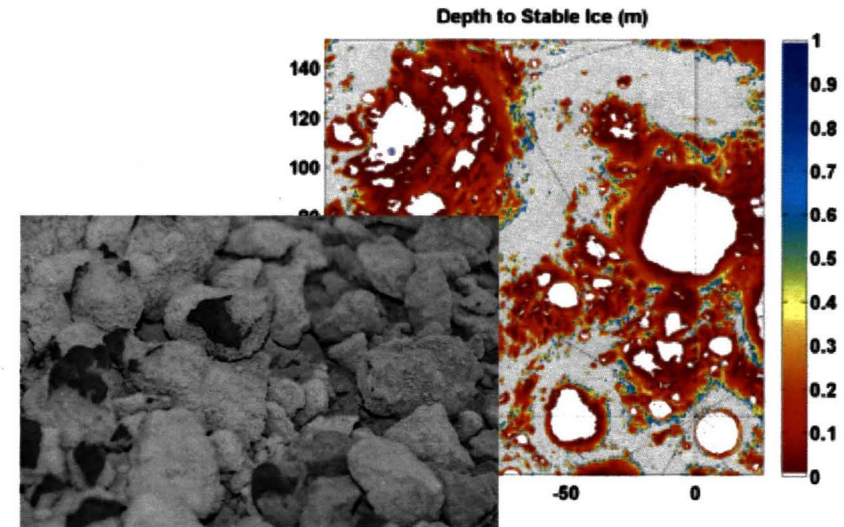


Task Lead: Rob Mueller (KSC)

Task Support: P. Abel (GRC), D. Magruder(JSC)

Current status of work:

- The recent “Lunar CRater Observation and Sensing Satellite” (LCROSS) mission has provided evidence for significant amounts of cold trapped volatiles in Cabeus crater near the Moon’s south pole.
- LRO/Diviner measurements of extremely cold lunar polar surface temperatures imply that volatiles can be stable outside of areas of strict permanent shadow.
- No deep regolith volatiles digging implement currently exists.
- Strong evidence exists that there is sub-surface water ice on Mars (Phoenix Mission and orbital sensing).
- The asteroid Ceres may have a water ice core.



FY12 Task Description:

- Generate concepts, and then design and fabricate a standardized, universal interface for a percussive excavation End Effector (EE) that will attach to a positioning mechanism developed in Task 3.3.2.
- The EE will leverage off work done in Task 3.3.4 (VIPER) by using percussive excavation methods that have been developed by HRS in FY11 and in partnership with Honeybee Robotics in a Phase II SBIR.
- Volatiles capture and transfer will be addressed as well as deep digging in highly consolidated regolith.
- The end product will be a deep digging EE for the Centaur 2 (C2) mobility platform that can acquire volatiles in regolith at multiple destinations.

OCT Roadmap areas:

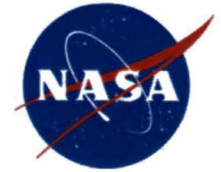
- TA 4.2.2 Below Surface Mobility
- TA 4.3.3 Modeling of contact dynamics
- TA 4.3.6 Robotic drilling and sample processing
- TA 7.1.1 Destination reconn, prospecting and mapping
- TA 7.1.2 Resource acquisition

Milestones:

- Jun 12: Centaur 2 implement interface for end effector fabricated
- Sep 12: End effector integrated onto GRC positioning mechanism
- FY13: Integration and testing on Centaur 2 base

Key Milestone – June 2012

Task 3.3.1: C2 Volatiles Mining End Effector Development



Objective: Deep digging end effector for the Centaur 2 mobility platform that can acquire volatiles in regolith at multiple destinations.

Key Accomplishments:

- Generate Centaur 2 deep digging concepts, and design and fabricate a standardized, universal interface for a percussive excavation end effector that will attach to a positioning mechanism developed in Task 3.3.2.
- Developed a deep digging end effector for the Centaur 2 mobility platform that can acquire volatiles in regolith

FY12 Milestones:

June 2012: Centaur 2 Implement Interface for End Effector Fabricated

September 2012: End Effector integrated onto GRC positioning mechanism

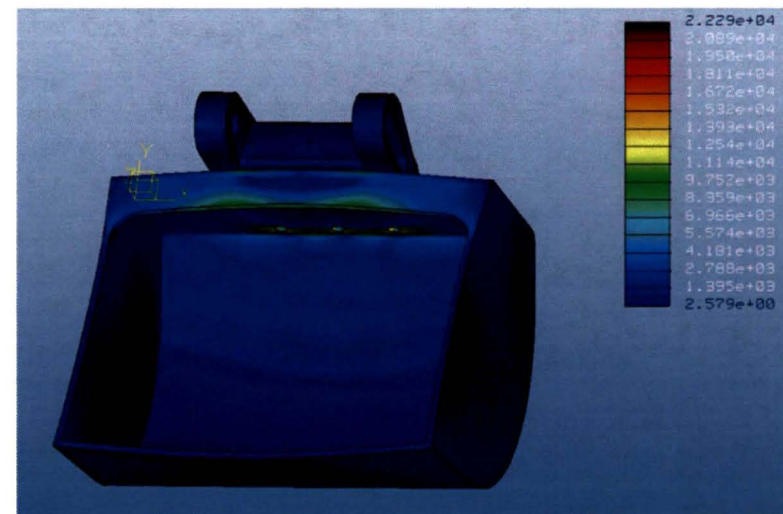
(Static bucket fabricated – Percussive bucket is in work)

Significance:

- Standard digging implements cannot penetrate the high strength of the icy regolith mixture.
- Volatiles capture and transfer will be addressed as well as deep digging in highly consolidated regolith.
- The end product will be a deep digging end effector for the Centaur 2 mobility platform that can acquire volatiles in regolith at multiple destinations.

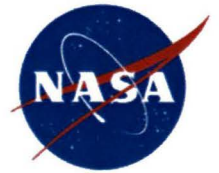


GRC/KSC End Effector Interface



KSC Static Digging Bucket

Task 3.3.1: C2 Volatiles Mining End Effector Development

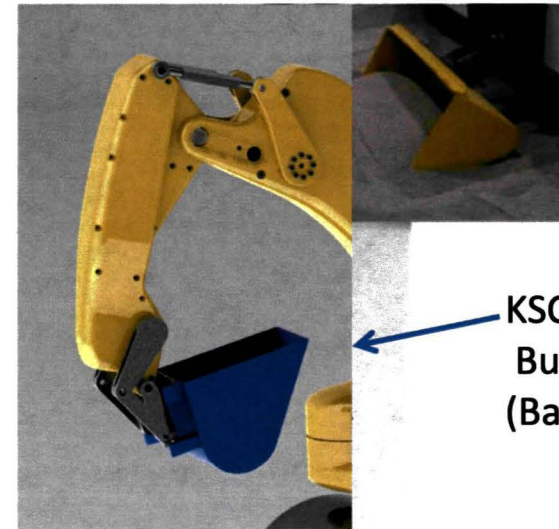


Task Lead: Rob Mueller (KSC)

Task Support: Abel (GRC), Magruder (JSC)

Current status of work:

- This task generated Centaur 2 deep digging concepts, and designed a standardized, universal interface for a percussive excavation end effector that will attach to the positioning mechanism developed in Task 3.3.2
- A static digging bucket which attaches to this interface was developed to use as a test baseline for excavation forces
- A percussive excavation mechanism was extensively tested in lunar and icy regolith simulant – testing revealed many challenges which were solved and will be implemented on C2



Static
Bucket
Baseline

KSC Percussive
Bucket
(Badger)

FY13 Task Description:

- Standard digging implements cannot penetrate the high strength of the icy regolith mixture. Volatiles capture and transfer will be addressed as well as deep digging in highly consolidated regolith. The end product will be a deep digging end effector (1 m)for the Centaur 2 mobility platform that can acquire volatiles in regolith at multiple destinations
- Percussive excavation methods can reduce excavation forces and was shown to be very effective during FY12 icy regolith testing. This method will be implemented and tested in FY13 with and without the GRC positioning arm in regolith simulant.

OCT Roadmap linkage:

TA 4.2.2 Below Surface Mobility
TA 4.3.3 Modeling of contact dynamics
TA 4.3.6 Robotics drilling and sample processing
TA 7.1.1 Destination recon, prospecting and mapping
TA 7.1.2 Resource acquisition

Milestones:

June 2013	Deliver percussive excavation end effector for the GRC C2 Arm for testing
Sept. 2013	Document Percussive Excavation End Effector Test Results

Task 3.3.4

Test trenching Using Existing Robots in Mixed and Icy Regolith Types

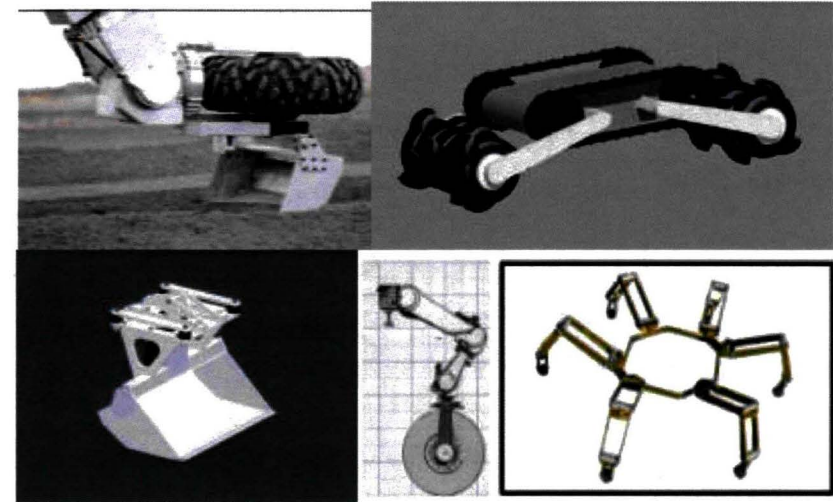


Task Lead: Rob Mueller (KSC)

Task Support: B. Wilcox (JPL), B. Bluethmann(JSC)

Current status of work:

- The Vibratory Impacting Percussive Excavator for Regolith (VIPER) implement was developed in FY2011 for use on an ATHLETE limb to dig trenches and other sub surface tasks in regolith.
- A NASA student project for the 2011 Lunabotics Mining Competition has developed and fabricated a very promising proof of concept prototype of a “zero-reaction force” regolith micro-excavator, which is small enough to fly on a X-Prize robotic pre-cursor mission.
- This robot is called Regolith Advanced Surface Systems Operations Rover (RASSOR).



FY12 Task Description:

- Test the existing VIPER and RASSOR prototypes in 1G and 1/6 G environments (off-loading).
- Acquire data and assess feasibility of digging in various environments: Asteroids, Mars, Moon.
- Investigate the capability of digging icy regolith with these prototypes.
- Improve understanding of low mass regolith excavation performance and requirements.
- Assess zero net reaction force digging concept of operations.

OCT Roadmap linkage:

TA 4.2.2 Below Surface Mobility

TA 4.3.5 Robotics drilling and sample processing

TA 7.1.1 Destination reconn, prospecting and mapping

TA 7.1.2 Resource acquisition

Milestones

Apr 12 Icy Regolith Test Beds Ready

Jul 12 VIPER and RASSOR Trenching Testing Completed

Sept 12 Data Analysis from VIPER and RASSOR Tests Completed

Key Milestone – July 2012

Task 3.3.4: Test trenching using existing robots in mixed & icy regolith types



Objective: Prove that trenching in Icy Regolith (10% water) with low reaction forces is possible – collect data

Key Accomplishments:

- Tested the existing VIPER and RASSOR prototypes in 1G and 1/6 G environments (off-loading)
- Investigated the capability of digging icy regolith with these prototypes
- Collected data for future design improvements

Milestones

Apr 2012: Icy Regolith Test Beds Ready

Jul 2012: Icy Regolith Trenching Testing Completed

Sept. 2012 : Icy Regolith Trenching Data Analysis Complete

Significance:

- Enables mining of Volatiles for ISRU
- Proves that lightweight robots can dig in 1/6th G
- Tests mechanisms for durability and failure modes

[Show Video of VIPER – Trenching Regolith](#)

[Show Video of VIPER – Trenching Icy Regolith](#)



Click images for video

VIPER Percussive Bucket Ice Digging



RASSOR Rotary Bucket Drum Ice Digging

Task 3.3.4:

Test Trenching using Existing Robots in Mixed and Icy Regolith Types



Task Lead: Rob Mueller (KSC)

Task Support: Brian Wilcox (JPL)

Current status of work:

During FY12, we tested the existing VIPER and RASSOR prototypes in 1G and 1/6 G environments (off-loading). We acquired data and assessed the feasibility of digging in various environments: Earth, Moon. The team also investigated the capability of digging icy regolith with these prototypes which improved understanding of low mass regolith excavation performance and requirements. An assessment was made of a zero net reaction force digging concept of operations, which was successful.

2 Papers will be presented at IEEE 2013



FY13 Task Description:

- Using FY12 excavator experience, and in collaboration with JPL, this task will produce an enhanced excavator system for deep trenching in regolith (> 1m depth)
- Water ice is known to exist on the Moon and Mars and trenching is one way of sub surface access to acquire the water ice for resource utilization and regolith / volatiles characterization.
- The lunar regolith trench that is left behind provides a valuable record of solar system history since the moon has not been weathered and eroded. Scientist and geologists (McKay, 2006) have stated that a 5 m deep, 100 m long trench is desirable for scientific study and possibly for shielding habitats
- Testing of these system will take place on ATHLETE at JPL and at KSC with RASSOR in Earth, Moon, Mars and Asteroid simulated reduced gravities.
- RASSOR II will be developed to incorporate lessons learned from RASSOR I and will be prototyped in a lean development process to benchmark timelines and methods

OCT Roadmap Linkage:

TA 4.2.2 Below Surface Mobility

TA 4.3.3 Modeling of contact dynamics

TA 4.3.6 Robotics drilling and sample processing

TA 7.1.1 Destination reconnaissance, prospecting and mapping

TA 7.1.2 Resource acquisition

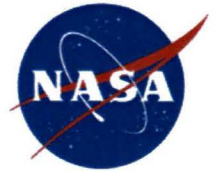
Milestones:

April 13 Test VIPER trenching in regolith with ATHLETE at JPL

June 13 Test RASSOR trenching at KSC in regolith with reduced gravity simulation

Sept. 13 Document trenching test results

Task X.X.X: Regolith and Volatiles Sample Acquisition on Comets, Asteroids, Mars and in Lunar Cold Traps



Task Lead: Rob Mueller

Task Support: JSC, JPL, GRC

Current status of work:

An existing KSC Internal Research & Development (IR&TD) project is investigating water ice prospecting, sampling and mining in polar lunar permanently shadowed regions (cold traps) using extreme access mobility methods. This project will leverage from this IR&TD work and develop regolith and volatiles sample acquisition systems for Comets, Asteroids, Mars and the Moon.



FY13 Task Description:

- The Japanese Hayabusa mission highlighted how difficult it is to acquire samples on ultra low gravity bodies – this task will investigate alternative and effective ways of acquiring and caching regolith samples for subsequent analysis
- The local environments and reduced gravity issues of operating on Comets, Asteroids, Mars and the Moon will be investigated and characterized
- Drills are typically used to acquire samples at depth, but this task will focus on alternative methods of acquiring samples such as sublimation hoods, self anchoring enclosed augers, pneumatic jet systems, scooping, trenching and tunneling
- Knowledge can Support Lunar/Asteroid Sample Return Mission Studies

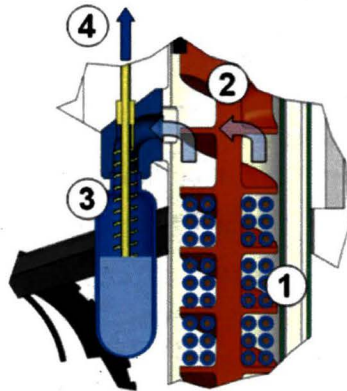
OCT Roadmap linkage:

- TA 4.2.1 Extreme terrain mobility
- TA 7.3.1 Surface mobility
- TA 4.3.3 Modeling of contact dynamics
- TA 4.3.6 Robotics drilling and sample processing
- TA 7.1.1 Destination reconnaissance, prospecting and mapping
- TA 7.1.2 Resource acquisition

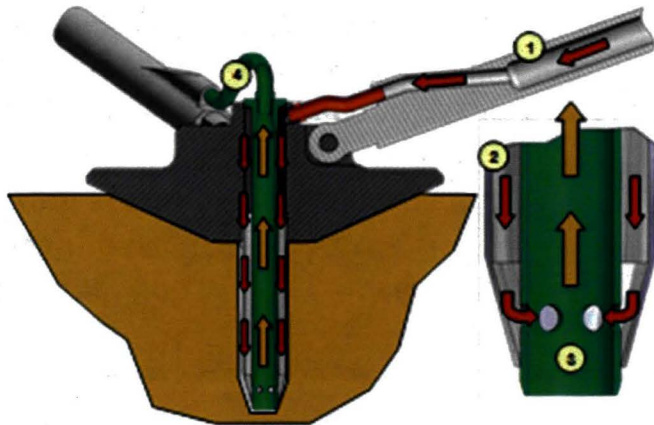
Milestones:

- February 2013 Regolith Sample Acquisition Concepts Generated
- June 2013 Bench top Sample Acquisition Demo
- Sept 2013 Airborne Sample Acquisition Demo

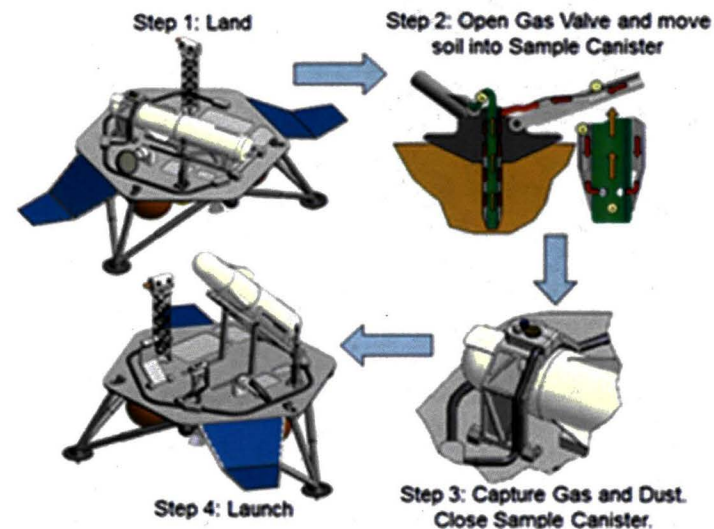
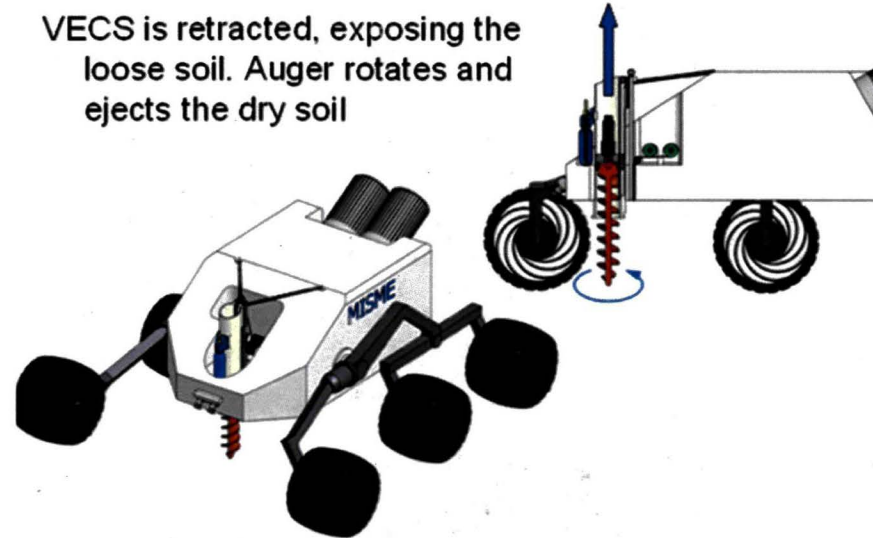
SBIR Infusion Example: KSC / Honeybee Collaborations



1. Icy soil is collected on auger flutes
2. Auger is heated, releasing water vapor from soil
3. Water vapor condenses on cold finger and collects inside a canister
4. Liquid water is pumped out of canister to holding tank inside rover Warm Electronics Box



VECS is retracted, exposing the loose soil. Auger rotates and ejects the dry soil



Education Outreach: NASA Lunabotics Mining Competition



Task Lead: Rob Mueller, Head Judge **PM:** Gloria Murphy

Task Support: NA - Volunteers

Current status of work:

NASA's Fourth Annual Lunabotics Mining Competition is a university-level competition designed to engage and retain students in science, technology, engineering and mathematics (STEM). NASA will directly benefit from the competition by encouraging the development of innovative lunar excavation concepts from universities which may result in clever ideas and solutions which could be applied to an actual lunar excavation device or payload.



Held Annually since 2010

FY13 Task Description:

The challenge is for students to design and build an excavator, called a Lunabot, that can mine and deposit a minimum of 10 kilograms of lunar simulant within 10 minutes. The complexities of the challenge include the abrasive characteristics of the BP-1, the weight and size limitations of the Lunabot, and the ability to telerobotically or autonomously control the Lunabot from a remote mission control center. This year the scoring for the mining category will not be based primarily on the amount of material excavated in the allowed time but instead will require teams to consider a number of design and operation factors such as dust tolerance and projection, communications, vehicle mass, energy/power required, and full autonomy. 50 teams are expected to register from all over the world to compete this year for the coveted grand prize, the Joe Kosmo Award for Excellence.

OCT Roadmap linkage:

TA 4.2.2 Below Surface Mobility
TA 4.3.6 Robotics drilling and sample processing
TA 7.1.1 Destination reconnaissance, prospecting and mapping
TA 7.1.2 Resource acquisition

Milestones:

Systems Engineering Paper April 22, 2013
Outreach Project Report April 22, 2013
Presentation (optional) April 22, 2013
Team Spirit All year
Rule #31 and #32 Documentation April 30, 2013
Team Check-in, Unload/Uncrate Lunabot May 20, 2013
Practice Days May 20 & 21, 2013
Competition Days May 22, 23, & 24, 2013

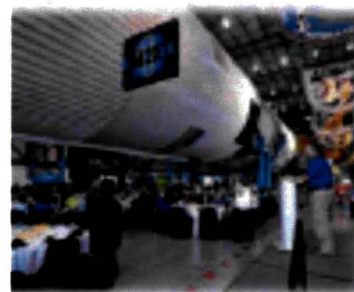


2012 LUNABOTICS

83,200 Google Search Results on "Lunabotics"
72 Teams registered
57 Teams participated at Lunabotics, KSC, Florida
55 Teams officially competed
791 Students participated
118 Faculty advisors participated
399 Volunteers and Staff
69 Volunteer Judges
14 Corporate Sponsors
2 Contributing Sponsors
61 University outreach reports completed
37 Presentations completed
8 Countries
28 USA states
60 tons of BP-1 regolith simulant
13 teams excavated the minimum of 10 kgs
706 kg of BP-1 mined
8 Job candidates selected by Caterpillar
Countless memories were made



hess



Lunabotics 2013 International University Teams



- 19 International Teams
- 9 Countries Represented
 - Australia (1)
 - Bangladesh (5)
 - Canada (3)
 - Columbia (2)
 - India (5)
 - Mexico (1)
 - Poland (1)
 - Tunisia (1)
 - USA (31)



- Goal: Every Continent Represented!

Good Press Coverage



Channel is offline

NE Live@Lunabotics Mining Competition

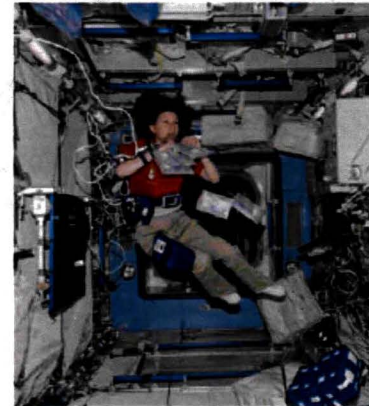
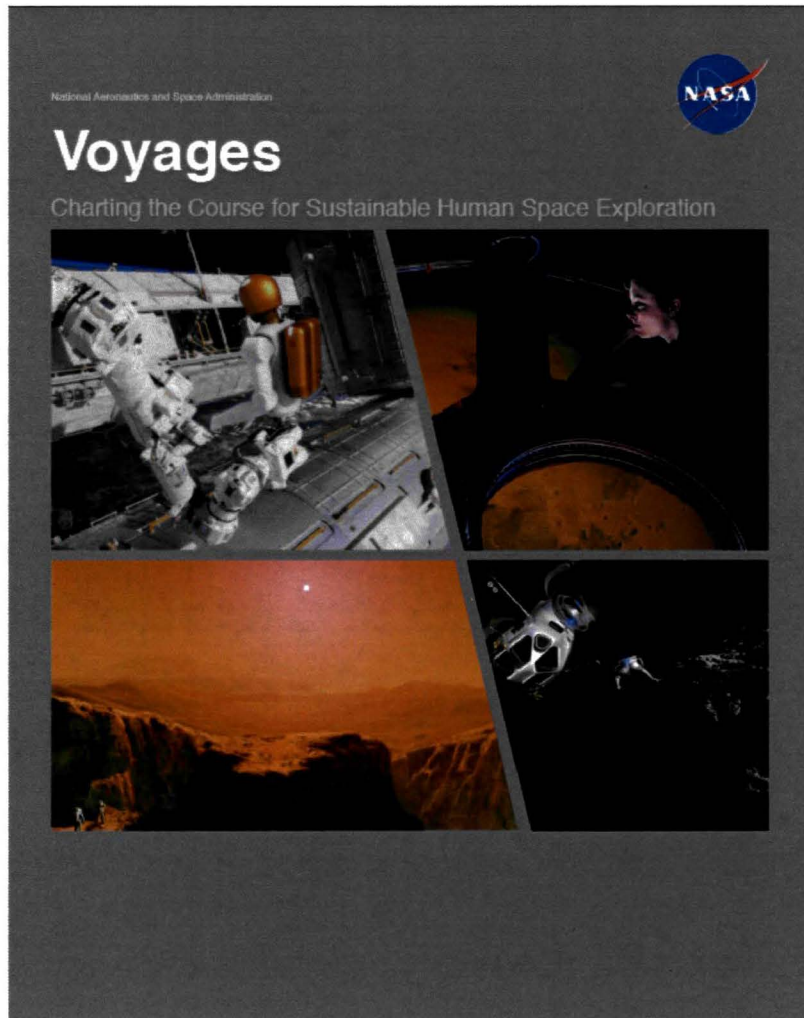
NASA_EDGE [Join Crowd](#)

[Pop out](#)

USTREAM



NASA HQ Support : Benefiting Humanity p. 5



NASA astronaut Cady Coleman participates in cardiovascular research on the ISS.



Student teams from around the world designed and built lunar mining technologies to compete in NASA's 2011 Lunabotics Mining Competition.

Benefiting Humanity

Our exploration efforts are rooted here on Earth, and they grow through continuous innovation and creativity. Innovations created to address the challenges of space exploration often lead to new and more sophisticated technologies that enable future missions—technologies that benefit both Earth and space applications around. Sensor-embedded materials designed to detect damage in launch vehicles do the same for bridges and buildings on Earth. Aerogel that insulates space suits is used on Earth for cryogenic storage or winter sports equipment. Sustainable systems for water recycling, waste management, and solar energy generation lower the cost of space exploration but also advance 'green' efforts here on Earth. Each new challenge we face in space brings with it the opportunity for technological advancement. With each innovation, we stand to gain knowledge to improve our lives now and in the future.

Human space exploration also provides opportunities to engage and inspire the next generations of explorers—in the hopes that they will embrace and continue the journey of discovery that we have started. By communicating the excitement of space exploration and the satisfaction of following curiosity to the gateway of discovery, we encourage students to pursue careers in science, technology, engineering, and mathematics to ensure the United States' scientific and economic future is a bright one.

Curiosity fuels the human spirit and is the driving force behind human space exploration. While each new discovery feeds our curiosity, it also increases our appetite to learn—and to apply what we have learned to improve life on Earth. The benefits and impacts of space exploration are far and wide—in fact, many of today's conveniences are actually the products of our past efforts to explore the unknown. NASA is poised to be at the forefront of this new chapter in space exploration and to reap the benefits of pursuing our curiosity.



HRS FY12 Continuation Review LaRC

John Dorsey
LaRC Center Point of Contact

Task: 3.1.2

Final Design of Long Reach Manipulator Joint Prototypes



Task Lead: John Dorsey (LaRC)

Task Support: Josh Mehling (JSC), Brian Wilcox (JPL)

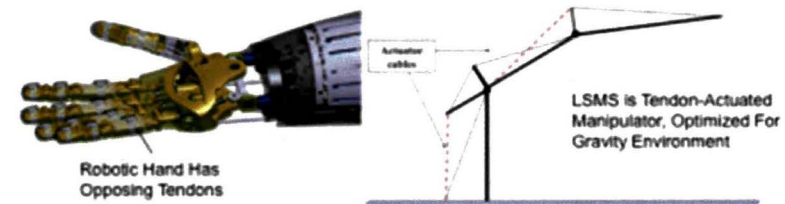
Current status of work:

Advanced long-reach high-performance manipulators are needed to support in-space operations such as NEO berthing, telescope assembly and satellite servicing.

- During FY11, requirements for advanced manipulators were compiled and two new manipulator structural architectures were conceived.
- Preliminary joint designs were completed for the two new manipulator concepts.
- End point control capability was developed using the LSMS test bed (to support use on the new manipulators).

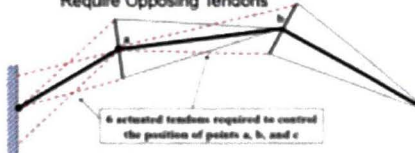
FY12 Task Description:

- Develop and evaluate two manipulator concepts and select one for final design.
- Develop the forward and inverse kinematic models for the selected manipulator.
- Fabricate a prototype model of the joint
- Perform kinematic/range of motion tests on the model.
- Initiate development of the necessary motor and controller architecture, hardware and software systems.
- Develop and test Sensor strategies required to operate the new manipulator, using the LSMS test bed.
- Initiate final manipulator design.

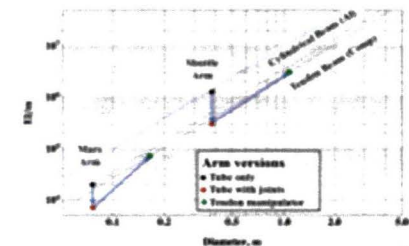


Long-Reach Tendon Actuated Manipulator Has Potential for Efficient Packaging and Light Mass.

Zero-g Tendon Driven Manipulator Will Require Opposing Tendons



Beam Bending Stiffness-Mass Efficiency Chart With Mars and Shuttle Arm Examples



OCT Roadmap Linkage:

TA04 Robotics Etc.

4.3 Manipulation;

2.3.1 SOMD Missions

2.3.2 ESMD Missions

2.3.3 SMD Missions.

OCT TA12 Materials, Structures, Etc.

2.1.1 Lightweight Structures

2.2.1 Lightweight Concepts.

KPPs:

Mass of objects that can be handled.

Volume of objects that can be handled.

Quantity of objects that can be handled in mission day

Milestones:

August 2012: Fabricate prototype model of critical joint.

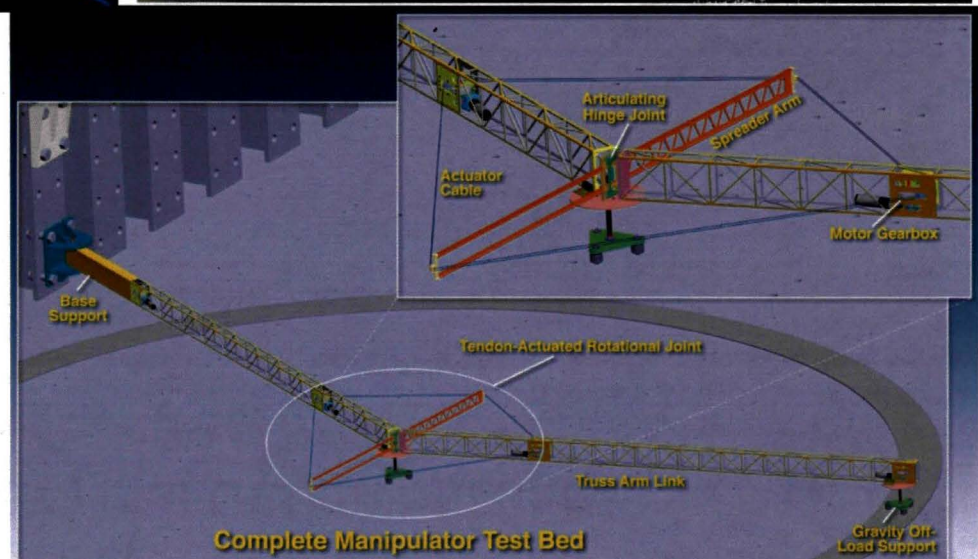
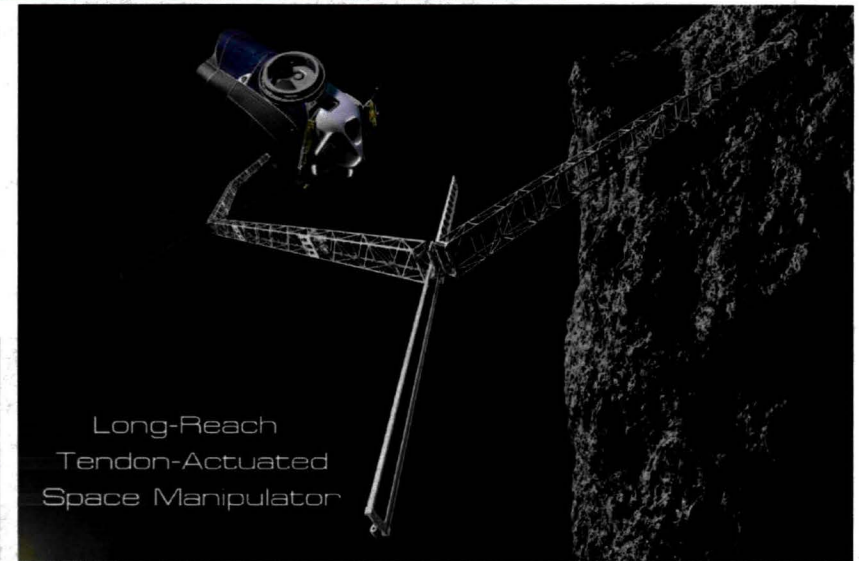
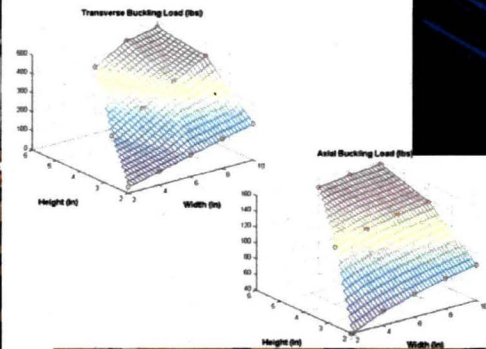
December 2012: Final design of long-reach in-space manipulator.

FY12 Accomplishments for Task 3.1.2: Final Design of Long Reach Manipulator Joint Prototypes



Long-Reach Tendon-Actuated Space Manipulator Development

- Concepts & applications (SAA with Altius Space Machines)
- Hardware design and fabrication
- Structural analysis
- Test Bed development

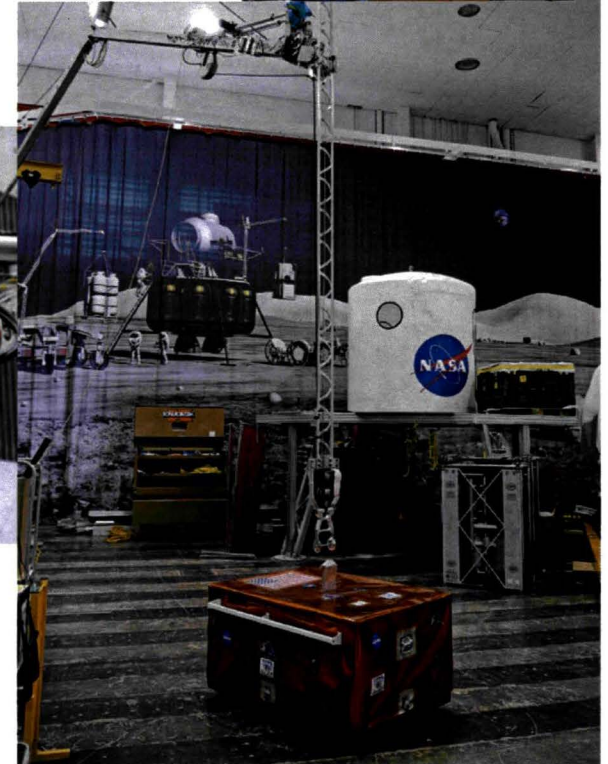
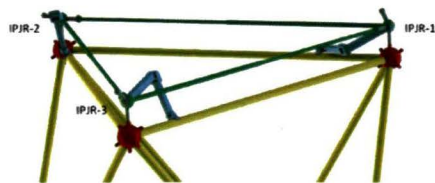
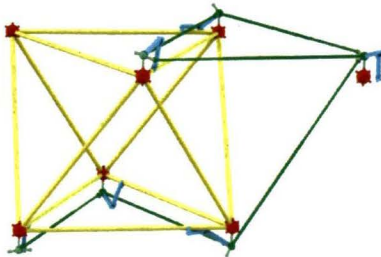
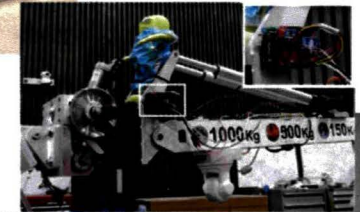
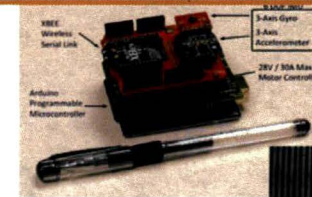


FY12 Accomplishments for Task 3.1.2: Final Design of Long Reach Manipulator Joint Prototypes



Tools and Operations Development

- End effector and tool hardware development
- Controls and operations development
- OCT Graduate Fellow Research
 - In-Space assembly concepts
 - Intelligent Precision Jigging Robots and supporting capabilities development



FY12 Accomplishments for Task 3.1.2: Final Design of Long Reach Manipulator Joint Prototypes



Task Lead: John Dorsey (LaRC)

Task Support: Erik Komendera (U. of Col.)

Current status of work:

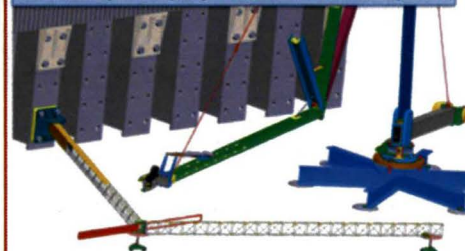
Long-reach high-performance manipulators and robotic infrastructure are needed for space operations in berthing, servicing and large space telescope assembly. During FY12:

- Design was completed for a tendon-actuated joint for a long-reach manipulator, a joint was fabricated, and range-of-motion tests initiated.
- Concepts for Intelligent Precision Jigging Robots (IPJRs) that aid in assembly were developed.
- Capabilities for robotic welding and IPJR manipulation were developed.

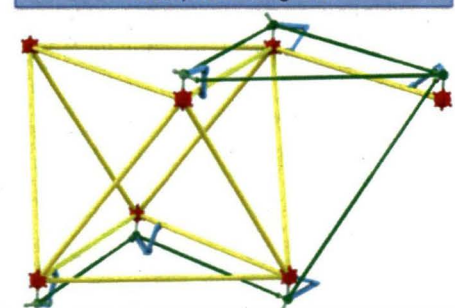
Task Description:

- Results from the FY12 joint prototype tests will be used to inform the design of a prototype long-reach in-space manipulator followed by fabrication and assembly of a representative section of the manipulator.
- Final design will be completed for prototype IPJRs and hardware fabricated. The IPJRs will be a key component used to demonstrate robotic assembly of a telescope support structure (a 2D planar triangular truss).
- The LSMS robot, previously developed under HRS will aid in the assembly experiment by serving as an auxiliary long-reach manipulator that will relocate the IPJRs and perform welding of the truss structure.

Tendon-Actuated Joint Prototype (for Space Manipulator) Layout in LaRC Laboratory



Intelligent Precision Jigging Robots (IPJRs – in Green) Assembling Truss



OCT TABS Elements:

TA 4.3	Manipulation
TA 4.3.1	Robot Arms
TA 2.3.2	ESMD Missions
TA 2.3.3	SMD Missions
TA 12.1	Lightweight Structures/Concepts

Milestones:

Dec 2012	Final design: long-reach manipulator
Jan 2013	Final design: 2D truss assembly experiment
Aug 2013	Experimental validation: 2D truss assembly
Sep 2013	Complete assembly of long-reach manipulator prototype section

Summary



- Every HRS task maps to a plausible mission
- One of the strengths of HRS is its ability to adapt core common robotic technologies to a variety of missions as they emerge
- As the agency defines its next set of missions, there will be more robots, not less